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Evaluation of noise dose measuring techniques and typical noise exposures of snowmobile and motorcycle operators.

Thomas N. Moore
University of Windsor

EVALUATION OF NOISE DOSE MEASURING TECHNIQUES AND TYPICAL NOISE EXPOSURES OF SNOWMOBILE AND MOTORCYCLE OPERATORS

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by

Thomas N. Moore

Windsor, Ontario, Canada

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TO MY WIFE

ABSTRACT

The noise exposure of snowmobile and motorcycle operators is studied using both commercially available noise dosimeters and a unique monitoring system known as an "ear bug".

In addition, the general performance of the dosimeters, the body baffle effects, and the attenuation characteristics of particular crash helmets are studied to provide a basis for evaluating their influence on operator noise dose.

The integration performance of the dosimeters purchased for this study is found to fall within the limits allowed by ANSI SI.4-1971 Type 2 A-weighting tolerances. The effect of incident sound level and duty cycle (down to 50%) is shown to be insignificant. The dosimeters' performance improves with increase in incident sound frequency up to 800 Hz.

The body baffle effect is shown to be of significance, although mounting the monitor microphone at the ear is found to permit the effects of sound incidence, sound source position, and the effects of clothing variations to be ignored for practical measurements.

The helmets tested are shown to be generally poor attenuators of the vehicle noise. Although significant transmission loss is produced with broadband noise, it is negligibly small for low frequency pure tone noise. The pure tone transmission

loss stays small and reasonably constant up to about 600 Hz and then increases rapidly. Also, helmet transmission loss is poorest for sound incident from the rear.

Both snowmobile and motorcycle operators are found to be exposed to potentially damaging noise levels with the snowmobile drivers typically receiving the higher noise exposure. The vehicle noise is predominated by discrete low frequency components. At vehicle speeds above about 40 mph wind noise becomes a significant contributor to the overall exposure. The results also indicate that the noise dose received by the operator depends on characteristics unique to the individual such as body build, riding posture, etc.

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NOMENCLATURE

C_i	actual expsoure time at a particular sound pressure level	(hr.)
dBA	a decibel unit frequency weighted in accordance with standardized "A" relative response	
D	noise dose in percent	(%)
ISO_8	equivalent eight hour ISO noise dose	
Leq	energy equivalent sound pressure level	(dBA)
L_i	a particular sound pressure level	(dBA)
L_j	midpoint sound pressure level for a particular range	(dBA)
NIPTS	noise induced permanent threshold shift	(dB)
NITTS	noise induced temporary threshold shift	(dB)
$OSHA_8$	equivalent eight hour OSHA noise dose	(%)
p_j	midpoint sound pressure for a particular range	(N/m^2)
p_o	reference sound pressure of 2×10^{-5}	(N/m^2)
p(t)	time varying sound pressure	(N/m^2)
q	noise dose intensity - time trading parameter (allowable dBA increase in level per halving of time duration)	
SPL	sound pressure level	(dBA)
t	time	(hr.)
t_i	actual exposure time at a particular sound pressure level	(hr.)
t_j	actual exposure time in a particular sound level range	(hr.)
T	total time duration of a particular measurement	(hr.)
T_i	allowable time for 100% exposure at a particular sound pressure level	(hr.)

TTS	temporary threshold shift	(dB)
TTS_2	temporary threshold shift measured two minutes after termination of noise exposure	(dB)

CHAPTER I

INTRODUCTION

In recent years much effort has been directed at limiting the noise exposure of industrial workers to what is now recognized as damaging noise levels. Legislation has forced industrial concerns to establish noise control programs which require quieting existing processes, setting standards for purchase of "quiet" machines, and provision and utilization of any other methods required to bring the noise exposure of employees within those limits specified by law.

Additional legislation has been aimed at noise emission from transportation vehicles (such as aircraft, trucks, cars, trains, motorcycles and snowmobiles) and certain stationary noise sources (such as portable air compressors). The thrust of this particular legislation has been to limit the amount of noise radiated from these devices to people not directly associated with their operation, such as those living in a house near an expressway, walking on a city street, enjoying a stroll in the woods etc. That is to say, truck drivers are not necessarily protected from damaging noise levels in the cab of their truck, even though the vehicle may meet all existing noise emission standards.

There have been standards proposed for in-cab noise levels in trucks, but the relation between these levels and the actual noise exposure during an actual operating mode is not yet clear. With respect to motorcycles and snowmobiles, very little work has been done to determine the noise exposure of the operators of these vehicles.

It is this area of operator noise exposure which will be of interest in this study. The particular area of study will be the noise exposure of snowmobile and motorcycle operators and the methods available to measure this exposure.

The initial sections of this study will be concerned with the performance of available monitoring instruments under laboratory conditions, the effects of the body on the sound field sensed by monitor microphones, and possible noise attenuation due to the use of crash helmets, which are required to be worn by law. The final section will detail actual noise exposure of operators under normal operating conditions.

In addition, a section of this study has been devoted to the effects of noise on people and also the concept of "noise dose" and "energy equivalent sound pressure level".

The section on noise and its effects on people was included to permit a broad overview of the hazards presented by noise and allow the reader to gain some insight into the basis for present noise standards. In addition, this information should permit the reader to make reasonable judgements as to the significance of the data presented later in this study.

The concepts of "noise dose" and "energy equivalent sound pressure level" are basic to an understanding of the information presented and, as such, have been dealt with in detail.

CHAPTER II

NOISE EXPOSURE: ITS EFFECTS AND MEASUREMENT

PART I

NOISE AND ITS EFFECTS ON PEOPLE

2.1 Introduction

If all the world's a stage on which to play out our lives, then we are often lucky if the audience can hear our soliloquy above the constant din in this theatre known as the 20th century. Today, it is noise which pervades our lives. From the great outdoors to the bedrooms of our homes, unwanted sounds force their attentions on our beleagured senses.

Early in the Industrial Revolution, with its introduction of mechanization in to the work shop, only those employed in factories suffered the effects of noise exposure. Now, however, the spread of mechanization has brought noise into our neighbourhoods, our homes and even our recreational activities.

The deleterious effects of noise on people have been grouped into three categories (1);

1) Effects that are clear, quantifiable and measurable such as hearing loss and cochlear injury following prolonged exposure to intense noise or reduction of speech intelligibility in the presence of noise.

2) Effects that are less easily quantifiable because of verbal ambiguity or situational and attitudinal components, such as noisiness, annoyance and community response.
3) Effects that are now suspected of occuring or suggested by preliminary observations such as decrease in performance, systemic patho-physiological changes and sleep interference.

2.2 Ear Damage and Hearing Loss

Probably the most significant health problem created by noise is hearing loss and it is this factor which will be discussed first.

Before attempting to review the literature on hearing damage, a short discussion of how the ear functions and what constitutes ear damage is in order. For an extremely detailed review see Hermann (2).

Although the outer ear, eardrum, and middle ear are almost never damaged by exposure to intense noise the eardrum can be ruptured by extremely intense noise and blasts (acoustic trauma) although, fortunately, this is rare.

The primary site of auditory injury is the receptor organ of the inner ear, that is, the organ of Corti. Basically damage occurs through damage of sensory hair cells and collapse or total destruction of sections of the organ of Corti. Auditory nerves may also degenerate.

The magnitude of injury to the inner ear and the associated hearing loss depend not only on the severity of the injury at any one location but also on the spread of the injury along the length of the organ of Corti.

Many theories have been proposed to explain noise-induced cochlear injuries but no matter what theory is eventually found to be correct, certain facts are established beyond doubt. "Excessive exposure to noise leads to the destruction of the primary auditory receptor cells, the hair cells. There can be other injuries to the organ of Corti that can range from mild distortion of its structure to collapse or complete degeneration. The auditory neurons may also degenerate. All of these cells are highly specialized. Once these cells are destroyed, they do not regnerate and cannot be stimulated to regenerate; they are lost forever."(3)

Fosbroke (4) in 1831 stated: "The blacksmiths' deafness is a consequence of their employment; it creeps on them gradually, in general at about forty or fifty years of age. At first the patient is insensible of weak impressions of sound; the deafness increases with a ringing and noise in the ears, ...". Thus, although industrial noise exposure has been recognized as the cause of occupational-deafness for many years, it is only in the last twenty years or so that a large body of knowledge has been developed.

Perhaps at this point it should be noted that there are factors other than occupational noise exposure which contribute to permanent reduction in hearing acuity. The most important of these additional factors is presbycusis, while a secondary factor might be termed "sociocusis". Presbycusis is the term used to describe the increase in hearing threshold due to aging, while sociocusis refers to the noise exposure during everyday life and social interaction. These two effects are extremely difficult to separate. Even if separable, it is not entirely clear how they would be applied in correcting hearing loss data.

Since hearing loss due to occupational noise exposure takes place over an extended period of time the resulting threshold shift contains a mixture of presbyacusis which must be removed. The standard assumption is that they are additive. Due to the great variation in individuals, it is often the median presbyacusis that it used as the correction, and any remaining threshold shift is attributed to noise exposure. This procedure has been criticized by Passchier-Vermeer who suggests instead a correction to each separate centile group of a distribution.

2.3 Steady-State Noise Exposure

A large number of papers concerning the influence of occupational noise exposure on hearing have been published but only in recent years have attempts been made (Baughn (5), Robinson (6), Passchier-Vermeer (7)) to determine from field investigations the relationships between steady-state noise and resulting hearing loss. Studies by Burns (8), Guignard (9), Johnson (10), Passchier-Vermeer (11) and Robinson (12) have shown it is possible to base permissible noise exposure on noise-induced permanent threshold shift (NIPTS). Previously limits had been based on a hypothecial relationship between noise-induced temporary theshold shift (NITTS) of young people with normal hearing exposed once to a given noise, and the NIPTS of people occupationally exposed to that noise each workday for many years. This was in spite of the fact that only for steady state noise has a relation been shown between NIPTS and NITTS, and this only at 4000 Hz (13). At other frequencies the relationship between NIPTS and NITTS in steady-state noise is still uncertain.

Using the data of Passchier-Vermeer (7) and Robinson (14) the Environmental Protection Agency (EPA) has found only small NIPTS for continuous exposure to a sound level of 80 dB(A) (15). For the frequencies of 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz, the median NIPTS was less than a decibel for the mid-frequencies, and only reaches 5 dB in the high frequencies after 40 years of exposure. Although more hearing loss is incurred by the 10 percent most susceptible (the 90th percentile), losses due to 80 dB(A) can still be considered slight. An exposure level of 85 dB(A) produces nearly twice as much NIPTS as the 80 dB(A) level and likewise the NIPTS for most frequencies doubles between 85 dB(A) and 90 dB(A) for both 10 and 40 years of exposure (15).

An interesting point can be seen in the data of Passchier-

Vermeer (7), Taylor, et. al. (15) and Nixon and Glorig (17) with respect to the increase of noise-induced threshold shift with time. The amount of threshold shift at 4000 Hz shows little increase after about 10 years of exposure, although the threshold shifts for lower frequencies continue to increase. Basically this brings about a "broadening" of the characteristic noise damage "4k Hz notch" as the lower and upper frequencies "catch-up" to the extremely rapid development of the 4000 Hz permanent threshold shift. Passchier-Vermeer (7) found that the median threshold shift seems to increase at a linear rate up to 40 years of exposure. At 500 Hz and 1000 Hz the rate after 10 years is only about a quarter of the initial rate of increase while at 3 k Hz it slows to about one tenth of the initial rate. At 6000 Hz and 8000 Hz it was indeterminate.

Basically the above discussion of NIPTS due to steady-state noise assumed a constant level noise exposure for eight hours a day (a working day) five days a week. What is the effect of changing the exposure time?

If the NIPTS level is fixed (such as by law) then the problem becomes one of determining the trading relationship between exposure time and sound level. Much legislation (Ontario Labour Safety Act, OSHA) has been enacted which allows a 5 dB increase in sound level with each factor of two reduction in exposure time. The supporting data for this relationship originated primarily from temporary threshold shift experiments. However this criteria has been called into question in recent years (15)(11). According to the EPA/AMRL criteria (18), the euqal energy rule (3 dB increase in level per halving of exposure time) is probably the best available method of predicting the effect of noise on hearing in the case of continuous noise with slow level functions (seconds to hours) during the workday, and its application is advocated by most contemporary researchers (8)(11)(19)(20).

2.4 Intermittent and Varying Noise Exposure

Little data has been generated which gives relations between exposures to varying or intermittent noise and noise-induced hearing loss (11). Early studies produced the damage risk criteria of the Committee on Hearing, Bioacoustics and Biomechanics of the National Academy of Science - National Research Council (CHABA) (21). The criteria, derived from data on temporary threshold shift, specify tolerable levels and durations of noise for 1-octave and 1/3-octave bands for a range of approximately 85 to 135 dB. They allow higher levels as the durations become shorter and recovery periods become longer.

Research has indicated that observed amounts of TTS_2 (temporary threshold shift after 2 minutes exposure to a given sound level) can be considerably higher than those predicted by the CHABA criteria (22). In addition to this, data by Ward (23) has cast some doubt on the validity of TTS_2 as an indicator of

NIPTS.

The CHABA criteria were later simplified to apply to the industrial situation by consolidating the 1/3-and 1-octave band long and short burst intermittent contours into one scheme combining dBA level total on-time and number of cycles (24).

The definition of "subjective quiet" as used in the CHABA criteria has caused much concern. The CHABA value for "effective quiet" is 85 to 89 dB depending on the octave band. However recent research by Schmidek et. al. (22)(25) has prompted E.P.A. to identify 50 dBA as a quiet requirement and the National Institute of Occupational Safety and Health (NIOSH) has identified a level of 65 dBA as a true "off-level". Both figures are considerably more conservative than the CHABA level.

At this time it would be advantageous to introduce the concept of "equivalent noise level" which is given the symbol "Leq". Basically Leq is the constant level which, in a given time interval, would be equivalent in energy to another that had a complicated level and exposure history.

In many cases it turns out that Leq is an adequate measure of probable damage, if we accept certain qualifications. Passchier-Vermeer (11) found that for levels above 100 dBA intermittent exposure will result in considerably less NIPTS than would be predicted from the Leq. This also applies to varying noise levels below 100 dBA equivalent levels. Above 100 dBA varying noise damage is closer to that predicted by Leq.

Ward (26) maintains that, based on NITTS experiments, Leq is more limited as a predictor of NIPTS than generally believed and that 10 dB error will be common when it is used. (The NIPTS may be 10 dB lower than predicted).

As noted by Passchier-Vermeer (11), contrary to the equal energy principle (which applied to TTS_2 states that TTS_2's resulting from exposures to noises with the same total sound energy are equal irrespective of the distribution of the energy over the time period), it has been shown in all TTS experiments that the distribution of the energy does indeed make a difference in the TTS_2 produced. It has also been shown that the same TTS_2 is caused by exposure to noises with quite different total sound energies.

2.5 Impulsive Noise

Two types of noise pulses have been catagorized by CHABA. The first are "A" pulses which consist of a positive pulse followed by a relatively small negative one. This type of pulse would be generated by rifle fire outdoors. Such "A" pulses are described by the A-duration which is the width of the positive pulse. The second type are "B" pulses. These pulses could be generated by hammering on metal or rifle fire indoors with reflecting walls. They involve considerable ringing or closely spaced echoes and are catagorized by a B-duration which is the total time that the envelope of the pressure fluctuation is within 20 dB of the peak pressure.

On the basis of temporary threshold shift data CHABA arrived at two exposure limits which can be regarded as equal damage contours using the A- and B-durations and peak pressures. However most of the recent evidence seems to indicate that for constant damage the equal energy principle holds (8)(27)(28)(29).

Little information exists on the long term exposure of humans to impulsive noise. However a recent study by Ceypek and Kuzniarz (30) details some interesting findings.

Basically the sample group had been exposed to impulsive noise for up to 30 years. The peak levels were between 127 and 134 dB with pulse durations of 100 to 200 msec., repetition rate of .5 to 2 per second and total impulses of between 3,000 and 10,000 per day. The background level was 110 dB.

The background noise itself should, considering the results of Johnson (10) for continuous noise, produce (with extrapolation) a hearing loss of 85 dB while only about 50 is actually obtained. Most of the loss occurs in the first two to four years which is contrary to the case of continuous noise. Additionally, according to information generated for continuous noise the 6000 Hz and 8000 Hz thresholds should show substantially less NIPTS than 4000 Hz but the actual case with impulsive noise permits no distinction. Obviously the need for more information in this area is great.

2.6 Hearing Impairment

Before leaving the subject of noise-induced hearing loss a discussion of what constitutes hearing impairment is in order.

In 1959 the American Academy of Opthalmology and Otolaryngology (AAOO) devised a formula for assessing a person's impairment of hearing which is still widely used. Basically the formula assumed;

1) The frequencies 500, 1000 and 2000 Hz cover the range of primary importance for hearing and understanding speech.
2) They are given equal weight and it is the average threshold shift of these three frequencies that is an adequate measure of a person's ability to understand everyday speech.
3) "Impairment" begins after a person has lost an average of 25 dB in the speech frequencies.
4) Each decibel loss above the 25 constitutes 1.5% impairment so that a loss of 92 dB in the speech frequencies constitutes total impairment.

Generally speaking this definition is not consistent with present-day knowledge of the relation between pure tone hearing levels and the ability to understand speech, particularly, everyday speech. It has been demonstrated that in order to understand speech in less than optimal conditions good hearing in the frequencies above 2000 Hz is very important (31)-(39). While these studies do not minimize the importance of good hearing in the mid-frequencies, they emphasize the previously underrated need for perception of frequencies in the range of 3000 Hz and 4000 Hz.

It would appear that the standards and guidelines proposed on these matters by not only AAOO but also ISO and NIOSH are not predicated on the more significant and relevant sources of presently available data. The result is "rather arbitrary and unrealistic definitions of hearing that have tended to lead to significant underestimation of the damaging effects of noise on hearing." (40)

2.7 Speech Interference

The dependence of the accuracy of speech communication on the speech signal-to-noise (S/N) ratio and the number of possible messages has been generally demonstrated. For a constant S/N ratio, intelligibility has been observed to decrease monotonically as the size of the message set increases (41).

Other factors also enter into speech intelligibility such as the characteristics of the people attempting to communicate (poor articulation, different dialects, lack of vocabulary, age and hearing damage) and the situational factors (message predictability, opportunity for lip reading, spatial arrangements, reverberation and kind of noise).

Certainly it can be agreed that, as stated by Miller (3); "In a highly intellectual, technical society, speech communication plays an extremely important role. Background noise can influence the accuracy, frequency, and quality of verbal exchange. In excessive background noise, formal education in schools, occupational efficiency, family life styles, and the quality of relaxation can all be adversely affected.

2.8 Interference with Sleep

We are all aware that sound can interfere with sleep since almost all of us have been wakened or kept from falling asleep by loud, strange, frightening, or annoying sounds. Yet it also appears that one can "get used to" sounds and sleep through them.

People used to quiet surroundings may have trouble sleeping in relatively noisy surroundings (such as a rural resident sleeping in an urban environment) or vice versa. A mother will wake to a slight stirring of her child yet sleep through a thunderstorm. Although the relations between exposure to sound and the quality of a night's sleep are complicated, research is beginning to provide some insight into the many factors involved in this relationship.

Generally the effects of relatively brief noises (3 min. or less) on a person sleeping in a quiet environment have been studied most thoroughly. The results indicate that the percentage of wakings depends not only of the intensity of the sound but also on the definitions of "waking", the motivation of the subject to wake in response to sound, and the sleep stages (I, II, III, IV or I-REM) when the stimulus is presented.

Studies by Schieber, Mery and Muzet (42) strongly suggest that fluctuations in the noise levels and degree of fluctuation are important factors in determining sleep disturbance by sound.

The effect of pitch, timbre and temporal structure in sleep disturbance (or enhancement) is not yet known.

A study by Williams et al. (43) shows that subjects who have been deprived of sleep require more intense noises for waking than normally rested subjects.

Other studies have shown that sleep disturbance by noise can also depend on the sex of the subject (44), the age of the subject (45)(46), the meaning of the stimulus (44)(47)(48), and the familiarity of the sounds (49).

Whether sleep disturbance constitutes a health hazard is debatable since normal persons who lose sleep compensate by spending more time in deep sleep, by becoming less responsive to external stimuli and by napping.

Yet everyday experience strongly supports the notion that a "good" sleep is important to one's feeling of well being. Certainly when noise conditions are sufficiently intense to disturb sleep on a regular, unrelenting basis then such sleep disturbance certainly constitutes a hazard to one's physical and mental health.

2.9 Annoyance

Annoyance is the term used to describe the composite effect of more primary effects such as interference with speech, concentration, relaxation, sleep or distracting, startling, frightening etc. effects.

Although annoyance can be measured with reasonable ease (by responses from individuals, juries, communities etc.) the task of quantifying the stimulus is much more difficult. In general Leq has been found to be a good approximation to the expected annoyance which will be caused, especially if corrections are made for time of day and pure tone content.

Much work remains to be done however, in quantifying human annoyance from noise. How much the degree of annoyance depends on situational variables such as work, recreation, sleep and listening to speech or music is a problem. In addition, identification and specification of annoyance produced by noise must consider the socioeconomic status of the recipients and the specific characteristics of the listeners.

2.10 Somatic Responses to Noise

Many somatic responses to noise exposure have been demonstrated. The responses have included vaso-constriction, muscle tension, and change in pulse frequency.

There is evidence that workers exposed to high levels of noise have a higher incidence of cardiovascular disorders; ear, nose and throat problems; and equilibrium disorders than do workers exposed to lower levels of noise (50)(51)(52)(53)(54).

As Miller (3) says, "While there are suggestions of relations between exposure to noise and the incidence of disease, the effects of noise on people have not been successfully measured in terms of "excess deaths" or "shortened lifespan" or "days of incapacitating illness". The only conclusively established effect of noise on health is that of noise-induced hearing loss".

2.11 Conclusion

Much work remains to be done in the area of noise and its effects on people. Standards and legislation enacted to protect us from the damaging effects of noise must be based on reliable and repeatable information, and not on arbitrary judgements stemming from confusing and conflicting information. Until we have come to terms with the problems of noise and its control, our sense of hearing will continue to suffer the assaults of unbridled noise.

PART II: NOISE EXPOSURE CRITERIA AND MEASUREMENT

2.12 Introduction

The preceeding section concerning the effects of noise on people provided background information which was considered necessary to a proper understanding of the proven and postulated hazards of noise. In addition, some of the controversy over the problems of determining a "safe" noise level for 8 hours continuous exposure and the trading relationship between exposure level and time of exposure for equal hazard were noted.

2.13 ISO and OSHA Criteria

Unfortunately, unanimous agreement has not been reached by researchers on the trading relationship to be used for either constant level noise of less than 8 hours duration or intermittent noise of constant level. The question is just as clouded for sound levels which vary continuously with time.

In spite of this uncertainty (or more correctly because of it) two basic criteria have emerged; ISO Standard 1999 (Assessment of Occupational Noise Exposure for Hearing Conservation Purposes) which has been adopted by most of Western Europe, and the Occupational Safety and Health Act (OSHA) criterion which is used in the U.S.A. and Canada.

Both criteria specify 90 dBA as the maximum allowable continuous noise level for an 8 hour workday. This is the only point of agreement. ISO 1999 uses a trading relationship which requires a halving of exposure time for every 3 dBA increase of level. Thus an exposure of 8 hours at 90 dBA is equivalent to 4 hours at 93 dBA. The OSHA criteria specifies a halving of exposure time for every 5 dBA increase in level.

The value for the number of dBA's corresponding to halving or doubling the time duration for a constant exposure is often given the symbol "q". Thus for ISO 1999 q = 3 and for OSHA q = 5.

The OSHA criterion covers the range of 90 to 115 dBA with no one permitted to be exposed to levels greater than 115 dBA. Below 90 dBA no limit is set on exposure time. ISO 1999 covers the range of 80 dBA and up. There is no upper level beyond which exposure is expressly forbidden, although the allowable exposure time does decrease rapidly with increase in level (e.g. exposure time of 95 seconds for 115 dBA level). Both criteria are shown graphically in Figure (1).

2.14 Noise Dose

Compliance with these criteria is obtained when the "daily noise dose" of any particular employee does not exceed 100%.

The daily noise dose is computed using the formula,

$$D = \left[\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n}\right] \times 100 \qquad (2.1)$$

The values of T_1, T_2, ... T_n are obtained from the following equations,

$$T_i = \frac{8}{2^{\left(\frac{L_i-90}{5}\right)}} \qquad i = 1,2,\ldots n \qquad (2.2)$$

$$T_i = \frac{80}{2^{\left(\frac{L_i-80}{3}\right)}} \qquad i = 1,2,\ldots n \qquad (2.3)$$

Equation (2.2) refers to the OSHA criterion and equation (2.3) refers to the ISO 1999 criterion.

2.15 Noise Dosimeters

Generally speaking the data required to calculate noise dose can be obtained by use of a sound level meter and a stop watch. This is especially true if the sound level is constant with time and the exposed person is stationary.

However, it is easy to imagine the problems which are encountered with this technique if the sound level varies with time and the employee must move from place to place during the day. Even tape recording the noise levels for later analysis would not easily solve the problem of employee movement away from the monitoring position.

Because of these problems the need for a portable instrument which could be worn on the person and which would continuously integrate the noise exposure was immediately recognized. The result has been a proliferation of small, easily used noise dose meters, or "dosimeters" as they are often called. These instruments provide a digital output of the daily noise dose in percent of allowable exposure.

Basically these dosimeters use the relationships,

$$D = 100 \int_{0}^{T/8} \left(\frac{P(t)}{.632}\right)^{1.2} dt \qquad (2.4)$$

or,

$$D = 100 \int_{0}^{T/8} \left(\frac{P(t)}{.632}\right)^{2} dt \qquad (2.5)$$

where equation (2.4) applies to OSHA and equation (2.5) applies to ISO 1999.

It can be shown that equations (2.4) and (2.5) are equivalent to equation (2.1) (See Appendix A).

2.16 <u>Energy Equivalent Sound Pressure Level</u>

It is often convenient to convert a time varying sound level to an energy equivalent continuous level for the measurement duration, usually called the "equivalent sound level" and given the symbol "Leq". Mathematically this may be expressed as,

$$Leq = 10 \log_{10} \left[\frac{1}{T} \int_{o}^{T} \left(\frac{P(t)}{P_o}\right)^2 dt\right] \qquad (2.6)$$

Equation (2.6) is often not convenient for determining Leq from dosimeters since their output is usually in the form of noise dose in percent of an allowable limit. It can be shown (See Appendix B) that,

$$Leq = 10 \log_{10} \left[\frac{D}{T}\right] + 79.02 \qquad (2.7)$$

or,

$$Leq = 16.67 \log_{10} \left[\frac{D}{T}\right] + 71.73 \qquad (2.8)$$

where equation (2.7) refers to the ISO standard and equation (2.8) refers to the OSHA standard. Thus knowing the noise dose, D, and the measuring duration, T, allows calculation of Leq.

Of course for a noise dose equal to zero these equations are not valid. In this case, it is known that for the OSHA criterion a noise dose of 0% means sound levels were below 90 dBA, while for the ISO criterion the levels would have been below 80 dBA. There is no Leq for a 0% noise dose reading.

2.17 Modified Dosimeters

In addition to dosimeters which follow the criteria outlined above, two modified dosimeters were used in this study.

These modified dosimeters were included to permit an evaluation of the noise dose received by recreational vehicle operators relative to standards which have been suggested for use based on some of the latest data available for noise induced hearing damage risk.

2.17.1 Modified OSHA Dosimeter

The modified OSHA dosimeter has had its range of integration extended to include 75 dBA to 125 dBA from the normal 90 dBA to 115 dBA. The value of 90 dBA for eight hours as 100% of the allowable noise exposure limit is the same for both the modified and unmodified dosimeters. Thus equations (2.2) and (2.8) remain valid for the modified OSHA dosimeter. Only their range of applicability has been extended.

2.17.2 Modified ISO Dosimeter

In the case of the modified ISO dosimeter the changes include shifting the integration range from the normal 80 to 130 dBA to 75 dBA to 125 dBA. Also the 100% expsoure limit has been changed to 85 dBA for 8 hours from the normal 90 dBA.

Thus equation (2.3) becomes,

$$T_i = \frac{8}{2^{\left(\frac{L_i - 85}{5}\right)}} \qquad i = 1,2,\ldots n \qquad (2.9)$$

and equation (2.7) becomes,

$$Leq = 10 \log_{10} \left[\frac{D}{T}\right] + 74.04 \qquad (2.10)$$

2.18 General Remarks on Dosimeters

In conclusion, a few general points should be made concerning noise dosimeters.

First it should be noted that dosimeters came into being due to a need in the industrial environment. Generally speaking this means measurements of diffuse noise fields produced by many broadband noise sources located in fairly well reflecting surroundings, and producing a reverberant field with a more or less haystack-shaped frequency spectrum.

For sound sources of high directionality and medium frequency under free-field conditions (typical for operators of snowmobiles and motorcycles), errors of 10 dB or more can be caused by body baffle effects when the monitor microphone is attached to the person. The actual errors due to this phenomenon are dealt with in some detail later in this study.

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CHAPTER III

LITERATURE SURVEY

The literature survey to follow has been divided into four areas which correspond to the four main topics covered in this study. It will begin with a summary of noise dosimeter evaluations which have been performed by various researchers. This will be followed by the results of body baffle studies, evaluations of the effectiveness of crash helmets as noise attenuators and finally the noise exposure of snowmobile and motorcycle riders.

3.1 Noise Dosimeter Performance

Confer et al. (55) tested a number of early model dosimeters. All dosimeters tested were designed to evaluate OSHA noise dose. The actual models tested were not revealed in the study but designated only by letters. These tests were run for the dosimeter microphones suspended in space. The results were not encouraging.

When exposed to broadband noise in a reverberant room the dosimeters tested showed significant differences in their responses. Narrowband noise tests showed that a number of dosimeters missed the 90 dBA cut-off by as much as 2 dBA, in the range of 125 Hz to 2000 Hz, for those designed to ANSI SI.4-1971 Type 2 "A"-weighting tolerances. Of course, this is within tolerance, but for the 2 dBA limit could permit an overexposure of 33%. A few dosimeters were found to take full advantage of the Type 2 tolerances with the result that for a frequency of 4000 Hz the cut-off was 5 dBA too high. This would result in a 100% overexposure for eight hours. Additional tests in an actual industrial environment showed poor reliability. A number of dosimeters broke down or operated intermittently.

Wilkerson (56) has published results of tests which he performed on nine dosimeters between April 1971 and May 1974. Once again the dosimeters are not specified by manufacturers and model, but only by letters. All dosimeters were OSHA standard.

Wilkerson found that continuous 1 KHz response, low level dropout, 115 dBA latch-in and frequency response were within ANSI SI.4-1971 Type 2 tolerances. In addition, dosimeter response to repeated tone bursts was determined for exposure to 1 KHz bursts of 1/16 to 1/2 second duration with varying duty cycles (duration of tone burst divided by the time from the start of one burst to the start of the next). The units tested showed a difference in indicated level relative to the continuous level of from -1 to -5 dBA at 50% duty cycle, and -5 to -12 dBA at 20% duty cycle. Wilkerson felt that, in general, dosimeter measurements would be at least as good as the results which could be obtained from sound level meter and time measurements.

A 1974 study by Stewart and Yen (57) included dosimeters from nine manufacturers. This study was primarily concerned with testing the A-weighted response and integration performance of wearable dosimeters. All dosimeters were found to meet the ANSI Type 2 A-weighting criteria, although some instruments were well within specification while others were borderline at some frequencies. With reference to integration performance (using "pink" noise,i.e.,equal energy per octave) substantial variation in measured exposure was found between instruments of different manufacture. Even for instruments of the same manufacture there were instances of large variation in calculated exposure. However in spite of this variation only 3 of 15 instruments tested failed to meet the integration criteria, which required the calculated exposure level to be within ± 2 dBA of the actual noise level. Thus for a nominal 100% exposure the instrument could read 75% to 133% and still be acceptable.

In a second paper presented by the same authors (58) at the Inter-Noise 74 Conference (essentially a synopsis of reference (57)) the authors were of the opinion that, for dosimeters, the response tolerance should be higher than that applicable to a type 2 sound level meter.

Up to this point all the studies cited have been concerned with dosimeters produced to evaluate the OSHA criterion noise dose, which is the accepted criterion in North America. However there is another standard used in Western Europe (it also has its advocates in North America) that is, ISO Standard 1999.

Since a person's ears must be assumed to be equally susceptible to damage regardless of where he may live, it is of interest to know what differences, if any, results when measuring noise dose using the two different values of "q". More specifically what is the difference in Leq for the two different q values when measuring different types of noise.

Just such a study was undertaken by Christensen (59). He found that when measuring fairly constant noise levels (i.e. slowly varying levels within a few dB) or rapidly repeated noise bursts (pulse repitition period less than 1 sec) ISO and OSHA measurements show little differences. Noise bursts repeated at greater intervals exhibit a noticeably lower reading for the OSHA dosimeter, while large burst intervals combined with great level variations give a still lower OSHA reading. Similar results were reported by Kihlman (60).

Thus although it would be desirable that various standards for noise dose measurements would lead to similar results in practice, the reality is that measurements according to OSHA may give an Leq 5 to 10 dBA lower than those according to ISO and there may, for a given exposure time, be up to 10 dBA difference in permitted level.

3.2 Body Baffle Effects

The wave nature of sound has long been recognized and with it, the fact that sound waves can experience constructive and destructive interference. Thus incident and reflected waves can interfere with each other to produce amplification or attenuation of the noise field at a particular point for particular frequencies. That is to say diffraction may occur.

Study of sound waves impinging on baffles by Sivian and O'Neil (61), in 1932, and Muller et al. (62), in 1938, demonstrated the now familiar pattern of undulations of relative sound pressure level with frequency. Thus for an 18" x 18" baffle, the relative sound pressure level increased to + 10 dB at 700 Hz, dropped to -3 dB at 1500 Hz, increased to +7 dB at 2000 Hz, dropped to +4 dB at 3000 Hz etc.

For the purposes of this review the relative sound pressure level is defined as the change in level between the undisturbed free-field or reverberant field and the level which exists with the introduction of an object.

Early work on hearing aid design by Carlisle and Mundel (63) showed the baffle effect of the human body. They used an artificial body (mannequin) to produce sound fields similar to those generated by human bodies.

Again, Hanson (64) studied the body baffle effect to determine its effect on hearing aid performance. These experiments were performed under basically free-field conditions. He found that the size of the person has some effect on the shape of particular details of the response curve, but in general the shape of the body baffle curve was very similar for all subjects. The position of the microphone on the person was found to affect the shape of the response curve to a great degree.

Nichols et al. (65) were interested in the manner in which the body baffle effect depends on the size of the wearer, the position of the microphone, and the nature of the sound field.

For the microphone at the centre of chest, free-field conditions, and subject facing sound source, the baffle effect was found to be quite similar for all persons tested in spite of the fact that their body builds were quite different. Dips in relative response of as much as 15 to 20 dB in the 800 to 2000 Hz range were noted. The spacing of the microphone from the body was found to have a definite influence on the baffle effect. Also, when the microphone was moved from centre chest to left breast-pocket a noticeable change in the baffle effect occurred.

Nichols noted that, qualitatively, the shapes of the curves for the body-baffle effect were in reasonable agreement with those which might be predicted from theory for rigid baffles of simpler geometrical form than that of the human body (59) (60), but due to the complex shape of the body, exact theoretical predictions would be extremely difficult.

Tests in sound fields of random incidence showed the body baffle effect to be very small although still apparent.

Muldoon (66) studied the body-baffle effect using an anthropometric test dummy in an effort to determine the optimum microphone position and orientation for noise exposure measurements.

Highly directional broadband noise was generated in an anechoic chamber with the resultant sound level at a point on the dummy measured with a 1" microphone. Basically Muldoon found that the proximity of the body does have a significant effect on the response of a microphone when worn by a subject in a highly directional noise field. Also the response characteristics change as a function of location and orientation of the microphone on the body. In general, for positions where the body is not acting as a barrier between the source and monitor microphone there was a pressure increase relative to the free field for the lower octave bands and a pressure decrease in the upper bands. When the body acted as a barrier, there was a pressure decrease relative to the free field in all bands reaching a maximum in the 4000 Hz band. Of all positions used for monitoring, Muldoon found the location of the microphone on top of the subject's shoulder to yield data most comparable with that obtained using a sound level meter (at the position to be occupied by the subject without the subject present). It should be noted that the "at ear" position was not tried in this study. No reason for this ommission was given, but was probably due to the size of the monitor microphone which would preclude comfortable use of this position in a real-life situation.

Hemingway and Christensen (67) reported on their study of the effects of placement on the response of Bruel and Kjaer noise dosimeters 4424 and 4425. These dosimeters employ a 1/2" condenser microphone. They found that for both diffuse and directional noise fields the smallest perturbations of the noise field occurred for the "at ear" position. Generally, broad-band diffuse noise fields showed the least effect while highly directional sound fields showed the greatest effect.

3.3 Noise Attenuation of Crash Helmets

Little information is presently available to permit evaluation of the sound attentuation properties of crash helmets. However, in 1974, Harrison (68) published the results of a study using sixteen different helmets with the subject riding a motorcycle. The noise levels generated at the ear while riding the motorcycle at various speeds were measured using a probe microphone. All helmets but one were equipped with a face shield (visor). The tests were then re-run without the use of helmets.

Harrison's results showed that the helmets tested provided insignificant hearing protection at speeds of 45 miles per hour or less and increasing hearing protection at higher speeds amounting to about 18 dBA reduction over no helmet conditions at 70 miles per hour. Also, type of helmet, type of eye protection or visor, and helmet fit all made insignificant differences in the noise experienced by the rider. At speeds of less than about 40 miles per hour, Harrison found most of the noise reaching the operator's ear to be radiated from the motorcycle itself. Above 40 miles per hour most of the noise reaching the operator's ear was wind noise caused by turbulence around the operator's head or helmet. Noise levels, with helmet on, of around 105 dBA were typical at 45 miles per hour. Levels as high as 111 dBA were recorded at 70 mph. Of course it should be noted that the motorcycle used was a high performance vehicle designed for both road and off-road use and may not be a typical noise source, although it should be remembered that Harrison found wind noise to be the largest contributor above 40 mph, and thus only difference in actual motorcycle noise would result in small changes to the overall sound level at the ear. It is interesting to note that an industrial worker would only be allowed 25 minutes of continuous exposure to noise of 111 dBA. Even for the 105 dBA level a continuous exposure time of only one hour would be allowed.

3.4 Noise Exposure of Snowmobile and Motorcycle Operators

3.4.1 Snowmobiles

A study done in 1970 by the National Research Council of Canada (69) mentioned at ear levels for snowmobile drivers of from 105 to 115 dBA to be typical of machines produced at that time. This would mean of course allowable continuous exposure times of from 1 hour to 15 minutes according to the OSHA criterion. Certainly the potential for severe hearing damage existed at that time.

In 1973 Curtis and Sauer (70) published a study of 10 snowmobiles. They did not however note the model years of the snowmobiles tested, although they were obviously no newer than 1973 models. The noise levels were measured with a sound level meter at a distance of one meter from the machine at a level approximately that of an operator's head. The snowmobiles were tested under stationary conditions with the track lifted off the ground. Basically they found that, under these conditions, snowmobile noise could be intense enough to produce a permanent hearing threshold shift with long-term exposure. The operator of the "average" snowmobile should not have been exposed to the snowmobile noise for more than one hour in any 24 hour period according to their study.

Chaney et al. (71) studied the TTS of a number of riders two minutes after exposure to snowmobile noise. The snowmobile models used ranged from 1968 to 1972 with varying engine displacements. The results showed TTS_2's for many of the riders approaching those which could result in hearing changes posing a significant handicap to speech recognition (as defined by the National Academy of Science, National Research Council Committee on Hearing, Bioacoustics and Biomechanics).

Harrison (72), using a microphone mounted in the operator's helmet, found at ear noise levels to average 97 dBA for 1968 to 1971 model snowmobiles which he tested. The maximum levels attained ranged from 105 to 115 dBA under normal operating conditions.

Of course, snowmobile manufacturers have been voluntarily reducing the noise levels of their machines and thus the hearing damage potential of recent snowmobile models is still open to question.

3.4.2 Motorcycles

The information available on the noise exposure of motorcycle operators under normal operating conditions is extremely limited.

The study by Harrison (68), cited earlier, noted that at ear levels of approximately 108 dBA were common at speeds of 55 mph. This level of noise is essentially independent of the motorcycle used since the predominant noise source at this speed is turbulent wind noise. Harrison does not provide any noise level distribution curves or mean values which might allow calculation of the operator noise exposure to be expected, since this study was not concerned with operator noise exposure per se but with crash helmet noise attentuation properties. However, the levels cited do provide some idea of the magnitude of the noise exposure.

A second study by Harrison (72) deals more specifically with the noise exposure of motorcycle operators. This study was cited previously, and as noted, the average at ear level was 97 dBA with a resultant allowable noise exposure time of 1.1 hours when evaluated using an 85 dBA "floor" (rather than the present OSHA 90 dBA for 8 hours). As Harrison notes, the exposure time is indicative of the amount of time per day that a vehicle could be operated every day, 5 days a week, 50 weeks a year, by a large population of typical working individuals, with only 15% of them suffering some hearing impairment as a result of this noise exposure.

This is rather unrealistic for motorcycle riders and the exposure time indicated could probably be increased by 50% or 100% without significantly increasing the danger of operator hearing impairment, according to Harrison. However, it should be noted that the noise dose received by motorcycle (or snowmobile for that matter) operators could very well be in addition to a rather severe noise dose accumulated at work, and thus pose a significant risk of hearing damage.

CHAPTER IV

INSTRUMENTATION

This chapter will detail the instrumentation employed in this study. Generally speaking the description will be brief, noting basic features of the instruments, the calibration procedure required for the instrument and any special features which may have been utilized. The description of the "ear bug" will be slightly more detailed since this is a specially built device which is not commercially available as a complete unit.

4.1 "Ear Bug" - Noise Level Monitoring System

Basically the ear bug consists of a subminiature microphone coupled to a modified commercial cassette tape recorder. This system allows a complete temporal record to be kept of the sound levels experienced at the microphone position and also allows analysis of the noise signal to be performed in the frequency domain by playing the taped results into a narrow-band real-time analyzer. An "exploded" view of the ear bug is shown in Figure (2).

The system works as follows. The microphone converts the sound pressure impinging on its sensing element to a voltage. This voltage is fed along a cable to an attenuation module. This module acts as an impedance matching device and as an attenuator which allows the dynamic range of the system to be "positioned" as desired. From the attenuator module the voltage signal enters the tape recorder where it is "weighted" by modifying the tape recorder frequency response and is then stored on magnetic tape for later reproduction.

The microphone used is a subminiature electret film microphone Model # 1785 from Knowles Electronics Inc. The overall dimensions of the microphone are 2.28 x 5.59 x 9.49 mm. The nominal supply voltage is 1.3 V DC with an output of from .2 to .9 V DC. The nominal output impedance is 4,000 ohms and the current drain is .01 to .05 mA DC (maximum). The frequency response is essentially flat from 3 Hz to 8,000 Hz.

The attentuator module is basically a voltage divider which permits impedance matching between the tape recorder and microphone, and attentuation of the voltage signal from the microphone to permit positioning of the voltage signal in the dynamic range of the tape recorder. The module consists of two commercial resistors. One resistor is positioned in the signal line between the microphone output and the tape recorder input. This resistor provides the impedance matching. The second resistor is connected from the tape recorder side of the "impedance resistor" to ground. Varying the value of this resistor changes the size of the voltage received by the tape recorder, for a constant sound level at the microphone. Thus by proper selection of this resistor the dynamic range of the ear bug system may be placed where desired. That is to say, for a particular value of this resistor, a dynamic range of 70 dBA to 100 dBA may be achieved. By changing this to a slightly smaller value, a range of from 85 to 115 dBA may be achieved. Thus, although we do not extend the dynamic range in absolute terms we can, in fact, position it to envelope the sound level range to be monitored. The resistors, their associated interconnections, and the input/output connectors are encased in polyester resin to provide a rugged and easily used unit. The attenuator modules are also color coded to identify the dynamic range which they provide.

The tape recorder used is a Sony TC 55 cassette tape recorder. It is powered by four "AA" batteries for field use, or may be run from a 120V AC line when used with the adaptor supplied. The overall dimensions of the recorder are 38 x 148 x 98 mm and it weighs 850 gm. The tape speed is 4.8 cm/sec. and the "as supplied" frequency response is essentially flat from 90 to 10,000 Hz. Continuous recording time with batteries is approximtely 2 hours (at room temperatures).

The "as supplied"tape recorder is modified to provide a 1.3 V DC voltage supply to power the ear bug microphone. In addition, the frequency response of the tape recorder is modified to provide "A"-weighting of the input signal.

With reference to the overall performance of the ear bug system, Figure (3) shows the dynamic response of the system for two different attenuator networks. A typical frequency response of the system is shown in Figure (4). The "A"-weighting curve as specified by ANSI Standard SI.4-1971, and the allowable tolerances for a Type 2 sound level meter are also shown in this figure. Any error in the weighting is removed by use of the B&K #125 1/3-octave spectrum shaper. In this case the output from the tape recorder is fed through the shaper before the signal is used for analysis. Work is continuing to remove errors in the A-weighting network greater than type 2 tolerances and thus the need for the spectrum shaper.

Due to the very small size of the ear bug microphone the directional characteristics of the system are very good. Figure (5) shows the output of the system for six different orientations. The output was not corrected with the spectrum shaper and thus the "waviness" of the response. The feature to note is the very close clustering of the points at each frequency tested. This shows that only very small changes occur in the noise level sensed for changes in microphone orientation. Only above a frequency of about 4000 Hz does the spread in levels begin to become significant (about 2 dBA). Generally speaking, frequencies above 4,000 to 5,000 Hz are of little significance to noise measurement of motorized vehicles powered by internal combustion engines. In addition, the "A" weighting tolerance at 5000 Hz is +6.0 to -5.0 dB and increases to +6.5 to - ∞ dB at 10,000 Hz. Relative to these tolerances the spread in levels due to orientation changes is very small.

The ear bug system is calibrated using the Bruel and Kjaer 4230 sound level calibrator. This calibrator provides a 94 dB acoustic signal at a frequency of 1000 Hz. Before measurements are made, this signal is played onto the tape, thus providing a 94 dBA reference signal when the data is replayed for analysis.

4.2 Bruel and Kjaer 4424 and 4425 Personal Noise Dose Meters

These units are small (33 x 75 x 115 mm) lightweight (280 gm) noise dosimeters which permit monitoring of noise dose according to OSHA (4425) or ISO (4424) standards. They are powered by two 9 V transistor batteries. Battery life is about 50 hours for continuous use and more for intermittent use. The sensing element is a 1/2" B&K condenser microphone type 4125. This microphone is relatively free of directional variations up to a frequency of 4000 Hz and has a flat free field frequency response of from 20 to 20,000 Hz. This microphone may be mounted directly on the dosimeter or remotely by means of a 1 m. cable. The input signal is A-weighted in accordance with IEC R123 (for the 4424) or ANSI S1.4-1971 Type S2A (for the 4425). The dosimeters have integral battery check indication and reset capability. Both dosimeters have an "alert light" which indicates that a noise level greater than 115 dBA "slow" has been sensed. This feature is required by the OSHA standard. The readout of the noise dose is by a 4 digit display mounted integrally in the dosimeter.

The 4424 has a dynamic range of 80 to 130 dBA "slow" including a 10 dB crest factor while the 4425 has a dynamic range of from 90 to 115 dBA "slow". The integration inhibition limit is 89 dBA for the 4425 and 80 dBA for the 4424. The linearity tolerance from microphone to display is $\pm$ 1 dBA.

The calibration procedure is identical for both dosimeters. The dosimeter is switched to the calibrate mode and the 4230 sound level calibrator is used to generate a 94 dB signal at the microphone. The calibration screw is then adjusted until the dosimeter counts 1% per second. This is easily determined using a stop watch (or wristwatch with a second hand for that matter) and watching the percent display of the dosimeter.

A rather unique feature of these dosimeters is their "accelerated mode" capability. When this feature is used the dosimeters count at a more rapid rate than is the case for the normal mode. The result is a noise dose which is 115 times greater than normal for the OSHA dosimeter and 125 times greater for the ISO dosimeter. This permits measurement of noise doses over very short periods of time.

The two modified dosimeters used in this study are basically identical to the standard dosimeters described above. The only differences are in their integration ranges and their 8 hour, 100% exposure level as detailed in Section 2.17.

4.3 General Radio Type 1944 Noise Dosimeter

The 1944 noise dosimeter consists of two individual instruments. The monitor is a small (56 x 124 x 23 mm) lightweight (210 gm) sensing instrument. It comes complete with a cable mounted ceramic microphone. This unit has no integral readout display. The monitor must be used with the companion indicator which contains the read-out display and reset functions. The monitor is powered by one 9 V battery which provides an operating life of up to 300 hours. The monitor is set to calculate OSHA standard noise dose only. The dynamic range is 90 to 115 dBA "slow" with a crest-factor capacity of greater than 15 dB. The specified accuracy is ± 1 dB at 115 dB and 1000 Hz. A-weighting is in accordance with ANSI Standard SI.4-1971 Type S2A.

The indicator is powered by four 1.5 V "C" batteries providing greater than 6 months normal service life. The indicator is rather large (279 x 186 x 54 mm) with a mass of 1.8 kgm. It provides a 3 digit LED display for readout of the noise dose contained in the monitor unit. The monitor must be mounted on a special connector unit of the indicator before the noise dose can be read out or the monitor reset. The indicator also provides the calibration signal for the monitor. A light on the indicator is activated if the 115 dBA "slow" level was exceded while the monitor was in use.

4.4 Bruel and Kjaer 4230 Sound Level Calibrator

The B&K 4230 Sound Level calibrator is a pocket size (110 mm long x 44 mm in diameter) battery operated unit. This unit is mounted directly on the microphone of the instrument to be calibrated. It provides a 94 dB signal at 1000 Hz. The accuracy of the sound pressure level is ± .5 dB from 0 to 50°C and the accuracy of the frequency is ± 1.5%. The sound pressure generated is independent of the microphone's volume and can thus be used to calibrate both 1" and 1/2" microphones (and also the ear bug microphones using a special adapter). The influence of static pressure is quite small being ± .05 dB/100 mbar from 500 to 1100 mbar.

4.5 Bruel and Kjaer 1022 Beat Frequency Oscillator

This unit provides sinusoidal signals with frequencies from 20 Hz to 20 KHz and can also supply frequency modulation if required. The frequency accuracy is better than 1% of scale reading. The output voltage is variable from 125 μV to 12.5 V in 10 dB steps with infinite level adjustment in each 10 dB range. The calibration procedure is very simple, using the power supply frequency as a comparison. The dimensions of the unit are 48 x 38 x 20 cm. The power supply is 120 V AC.

4.6 Bruel and Kjaer 2706 Power Amplifier

The 2706 provides a 75 Watt power output into a 3 ohm load. It has a frequency range from 10 Hz to 20 KHz and maximum voltage gain of 40 dB. Harmonic distortion is less than .5% from 20 Hz to 20 KHz at full capacity. A front panel light indicates output signal clipping. The overall dimensions are 13 x 21 x 20 cm. Power supply is 120 V AC.

4.7 University Sound Model CLC Weatherproof High Fidelity Speaker

This speaker has a low frequency cutoff of 85 Hz with a maximum sound pressure level of 110 dB at 1000 Hz, four feet on axis. Maximum power is 30 watts with an 8 ohm impedance.

4.8 Bruel and Kjaer 2619 Preamplifier

This preamplifier is one of a family designed especially to match the needs of the B&K condenser microphones. It is small (83 mm long x 12.7 mm diameter) and very rugged. The input impedance is 4 GΩ with an output impedance of less than 25 Ω. When coupled with a B&K 4145 condenser microphone its frequency response is flat from 5 Hz to 100 KHz. Attenuation is less than .03 dB and noise is less than 20 μV when used with a 1" microphone (such as a 4145). The preamplifier is attached to a 2m cable which is terminated with a B&K 7 pin connector which allows easy coupling to the B&K 2607 measuring amplifier and other B&K instruments.

4.9 Bruel and Kjaer 4145 1" Condenser Microphone Cartridge

The 4145 is a free-field microphone used for general and low sound level measurements. The polarization voltage is 200 V DC. The open circuit frequency response for free field 0^b incidence is generally 2.6 to 18.5 KHz(individually calibrated). Open circuit sensitivity is generally 50 mV/Pa (individually calibrated). The influence of vibration, for a 9.81 m/sec^2 acceleration in the axial direction, is 88 dB. The influence of static pressure is -1.8 dB/atm., while relative humidity will cause less than .1 dB change in the absence of condensation. The cartridge is 23.77 mm in diameter and 17 mm long.

4.10 Bruel and Kjaer 2607 Measuring Amplifier

The B&K 2607 measuring amplifier is basically a low noise, wide range calibrated voltmeter. The combination of five stages of signal amplification and two attenuation sections give high linearity of amplification with low noise and distortion. Overall amplification of 120 dB and attenuation of 150 dB in accurate 10 dB steps gives this instrument a voltage measuring range from 10 μV to 300 V full scale deflection. Signal to noise ratio is better than 80 dB for input signals higher than 30 mV. The 2607 also has low and high pass filters with cut-off frequencies of 22.4 KHz and 22.4 Hz, respectively, with slopes greater than 24 dB/octave. In addition, the A, B, C and D weighting networks are available. Both RMS and "Peak" values of a signal can be measured. Averaging times from .1 to 300 sec as well as "fast" and "slow" (per IEC, ANSI and DIN Recommendations for Precision Sound Level Meters) may be selected. A continuous -10 dB to +4 dB range of sensitivity adjustment is available from screw-driver operated potentiometers on the front panel. These adjustments permit meter scale calibration for a wide range of transducer sensitivities. Overall dimensions are 132 x 380 x 200 mm. The 2607 can be powered by 120 V AC or 12 V DC.

4.11 Bruel and Kjaer 2307 Graphic Level Recorder

The B&K 2307 can accurately record the RMS, Average or Peak level of an AC signal in the frequency range from 2Hz to 200 KHz and can also record DC signals. The dynamic range of the level recorder is determined by which of six available potentiometers is used. Various paper and writing speeds are available by setting the appropriate controls. Full scale response time can be as small as 50 m sec. Power supply is 120 V AC.

4.12 Bruel and Kjaer 4420 Statistical Distribution Analyzer

The B&K 4420 is used in conjunction with level recorder

2307 to produce a statistical distribution of a particular time varying signal. Basically the analyzer consists of a set of twelve contacts which are scanned by means of the writing arm of the level recorder thus enabling the recorded information to be resolved into twelve level bands, and a numerical display of the data to be presented. There are thirteen display windows; one displays the total count and each of the other twelve display the count for one of the twelve level bands. The built-in generator allows selection of one count every .1, .3, 1, 3 or 10 seconds.

For this report all data analysis using this instrument was run at the 10 counts per second rate (i.e. a count every .1 sec.). Depending on the potentiometer used in the level recorder the decibel range spanned by each of the twelve levels can be 1, 2.5, 5 or 7.5 dB. In the particular case of this study, the value of 2.5 dB was used at all times.

4.13 Bruel and Kjaer Model 125 Spectrum Shaper

The model 125 modifies or shapes the frequency spectrum of an input signal. The input signal feeds an amplifier which drives twenty-five 1/3-octave filters. Each filter feeds a separate buffer amplifier which couples each filter to its own slide attenuator. An output amplifier sums the signal outputs from each attenuator and also provides a low impedance driving source.

The twenty-five attenuator controls are mounted on the front panel in a single row. Each one controls the contributions of its associated 1/3-octave filter to the total output. Since the attenuators are logarithmic, the array forms a visible picture of the spectrum shape. The range of each attenuator is from +10 dB to -40 dB. The 1/3-octave filters are ANSI S1.11-1966 Standard Class III and range from 63 Hz to 10 KHz centre frequencies. The total dynamic operating range of this instrument is greater than 50 dB with an input selectable at 600 or 100 K ohms. The maximum attenuation slope of the filters is 50 dB per octave or greater. Power supply is 120 V AC.

4.14 <u>Bruel and Kjaer 1405 Noise Generator</u>

The noise generator type 1405 is designed to supply well defined white noise in the frequency range from 20 Hz to 100 KHz. The generator has a built-in -3 dB/octave filter which is used to weight the white noise in order to produce pink noise in the frequency range from 20 Hz to 50 KHz. The -3 dB/octave filter can be used separately, as can a built-in compression unit.

The white noise has a uniform spectral density of 10^{-4} V^2/Hz up to 50 KHz. The output of white noise in the frequency range from 20 Hz to 20 KHz is within $\pm$ 1 dB while the fall-off slope above 20 KHz is greater than 18 dB/octave.

The pink noise output is within $\pm$ 1 dB for the range 20 Hz to 50 KHz.

Signal-to-hum ratio is greater than 90 dB for white noise and greater than 70 dB for pink noise. Stability of the output is better than $\pm$ .3 dB in the range -10°C to 40°C. The output level ~~is~~ 3.16 V RMS, continuously variable down to 0 V.

Power supply is 120 V AC.

4.15 Spectral Dynamics SD 301 C Real Time Analyzer

The SD 301 C provides "real-time" narrow-band analysis of signals in the frequency domain. The output is a representation of the magnitude of the frequency components of an input signal. A total of 500 synthesized filters are used to analyze the time-compressed signal. Analysis may be performed in 10 ranges from 0 to 10 Hz to 0 to 50,000 Hz with filter bandwidths ranging from .03 Hz to 150 Hz. Frequency response is ± 1 dB over the entire frequency range with spectrum output linearity of ± .5% of full scale or ± 1 dB whichever is greater. Two equal sinusoids, spaced 2 filter bandwidths apart, when applied simultaneously to the SD 301 C will exhibit an average 6 dB valley between the spectral peaks. Filter response is at least -20 dB at a frequency removed from the centre frequency by 2 bandwidths and -40 dB at 4.5 bandwidths within ± 15%.

4.16 S.E. Laboratories Model S.E. Four-Eight Portable Tape Recorder

This is a four track, three speed tape recorder. Three of the channels are F.M. recording while the fourth is direct recording and used for voice-cue recording. Tape speed accuracy is better than .25%. At a tape speed of 38 cm/sec. the frequency response is D.C. to 5 KHz with a RMS signal-to-noise ratio of 44 dB, for the F.M. channels. Distortion is less than 1.2% with linearity of ± 1% of full scale.

CHAPTER V

PROCEDURE AND RESULTS

5.1 Noise Dosimeter Performance

Since noise dosimeters would be one of the instruments used to evaluate noise dose of snowmobile and motorcycle riders, it was decided that the performance of the Bruel & Kjaer and General Radio dosimeters, purchased for this study, should be checked for integration performance relative to ANSI SI.4-1971 Type 2 A-weighting tolerances. Three basic tests were to be performed;

(a) Constant sound pressure level for ~~a~~ known time at varying frequencies.

(b) Constant frequency at different sound levels for known times.

(c) Intermittent sound signals at constant frequency and constant peak level.

In addition to the above tests, the ease of field use, ease of calibration and long term durability were to be noted and reported on.

5.1.1 Procedure

A total of nine dosimeters were originally to be tested; three each of B&K 4424, B&K 4425 and GR 1944. However before testing of the dosimeters began, one of the GR 1944 dosimeters malfunctioned. Because of this only two G.R.

dosimeters were actually tested.

5.1.1.1 Plane-Wave Tube

To facilitate the study a plane-wave test chamber was constructed. Basically this consisted of a 3.0 m. long by .43 m. diameter cardboard tube. At one end of this tube was mounted a University Sound Model CLC high fidelity speaker. This tube was wrapped with glass fibre batts to reduce sound transmission into and out of the tube. The other end of the tube projected 1.4 m. into a .6 m square by 2.4 m. long plywood chamber which was lined with glass fibre and terminated with a .5 meter thick pad of glass fibre. This chamber thus acted as an anechoic termination and also permitted access to the test section of the plane-wave tube through a side access door. Figure (6) shows the overall test set-up with the speaker removed from the end of the tube. During testing the access opening was covered.

The actual test section was about .5 meter from the end of the tube which entered the plywood chamber. At this point the sound level was constant across the section within $\pm$ .2 dBA for frequencies up to 1,000 Hz. Above this frequency a constant sound level could not be achieved across the section. This was not an impediment since, due to the nature of recreational vehicle noise, the dosimeter performance at low frequencies only was of interest. Sound levels as high as 120 dBA could be produced at this section, with ambient levels of about 45 dBA.

5.1.1.2 Microphone Test Ring

To hold the dosimeter and monitor microphones at the test section a microphone ring was built. This consisted of an aluminum ring with six microphone mounting prongs spaced evenly about its diameter. Three monitor microphones were mounted on the ring every 120°. These microphones were used to monitor the actual sound pressure at the test section and to indicate the "flatness" of the sound field. The dosimeter microphones were mounted on the unused prongs. When mounted, all microphones directly faced the sound source. Figure (7) shows the ring with dosimeter and monitor microphones attached to the mounting prongs.

5.1.1.3 Basic Test Set-Up

The basic test set-up, complete with instrumentation is shown in the schematic of Figure (8). The B&K 1022 oscillator produced the desired pure tone signal which was fed to the B&K 2706 power amplifier and then to the speaker. The sound level produced at the test section was monitored by three B&K 4145 1" microphones mounted on B&K 2619 preamplifiers and feeding into three calibrated B&K 2607 measuring amplifiers. This permitted regulation of the test section sound level to the desired level and also indicated any variation in level across the section. A switch was mounted between the power amplifier output and the speaker thus allowing the signal to be turned on and off rapidly. In this manner the test section sound level could be set up with the dosimeters off. Then the signal to the speaker was turned off. Since the ambient level at the test section was no more than 45 dBA, the dosimeters could then be turned on but would not begin integrating since the ambient level was far below their integration inhibition levels. When the operator was ready the switch could be turned on and the speaker would produce the preset sound level at the test section. At the end of a predetermined time the switch would again be turned off and the test section level would drop to 45 dBA thus stopping dosimeter integration. The dosimeter readings could then be taken at leisure.

5.1.1.4 Test Groupings

The dosimeters were tested in two groups. The first group consisted of the five OSHA standard dosimeters (three B&K 4425's and two G.R. 1944's) while the second group consisted of the three B&K 4424's which are ISO standard. The tests performed on each group were identical in nature varying only slightly in actual test levels and time durations used. These differences were introduced to generate noise doses of reasonable magnitude in a reasonable length of time. Before all tests the dosimeters were calibrated to manufacturers specifications as were all monitor microphones.

5.1.1.5 Constant Sound Level-Varying Frequency

The first test consisted of producing a constant sound pressure level for a number of different frequencies ranging from 100 Hz to 800 Hz. This would permit comparison of the variation of indicated noise dose with input signal frequency. The variations could then be compared to variations which would be expected due to the tolerances on the dosimeters' A-weighting networks.

5.1.1.6 Constant Frequency-Increasing Sound Level

The next test sequence exposed the dosimeters to constant frequency signals which increased in magnitude in discrete steps. Any variation in nominal noise dose as a function of level increase could thus be detected.

5.1.1.7 Intermittent Noise Test

Constant frequency and peak level signals were used to determine if the noise dose calculated by the dosimeters was dependent on the duty cycle of the sound input. The frequency of the sound used was 200 Hz with an "off" period between bursts of 5 seconds. The duration of the bursts was varied from 5 sec to 60 seconds. In this case the intermittent sound levels were tape recorded using the S.E. Four-Eight and then played through the speaker. This freed the operator from the tedium (and probability of error) associated with switching the sound on and off every few seconds during a large number of tests.

5.1.1.8 Cold Tests

Before using the dosimeters to assess snowmobile operator noise exposure, the effect of low temperatures on dosimeter performance should be investigated. To this end, a series of simple tests were performed.

The dosimeters were given fresh batteries, calibrated, and then placed in a small refrigerator's freezer compartment. The temperature in this area was 0°C. The microphones of all the dosimeters were brought out of the refrigerator and remained at room temperature. After specified time intervals the calibration signal was again played into the dosimeters and any variation in indicated noise dose was noted.

5.1.2 Results and Discussion

5.1.2.1 Constant Sound Level-Varying Frequency

Figure (9) shows the results of the constant sound level-varying frequency tests for OSHA dosimeters. The abcissa is "Relative percentage noise dose" which is defined as the increase (+) or decrease (-) of the noise dose indicated by the dosimeters relative to the nominal noise dose. The shaded area shows the range of the relative noise dose permitted when the ANSI SI.4-1971 Type 2 A-weighting tolerance is applied for pure tone signals of 12 minute duration. The dashed lines represent the same tolerances for an 18 minute signal. It should be noted that the limits are not becoming more lax with time as might be thought at first glance. The tolerances shown for the 18 minute time period permit the same relative percentage error as does the 12 minute limit.

As an example, the nominal noise dose for a sound level of 100 dBA with a 12 minute duration is 10%. For a 100 Hz frequency the ANSI tolerance is ± 2.5 dB. This gives an upper noise dose of 14%. Thus the percentage error relative to the nominal noise dose is 40%. For the same signal of 18 minute duration the nominal noise dose is 15% with an upper tolerance limit of 21%. The relative percentage error is again 40%.

Only the results for two of the five OSHA dosimeters are shown in the figure. The results for the other three dosimeters are the same or slightly better than those shown.

It is obvious that only once did a dosimeter give a reading outside its allowable tolerance. This was the General Radio dosimeter denoted as meter #7 during testing. This may have been due to a chance variation, but it should be noted that this dosimeter at many points is either right on the upper tolerance limit or just under it. This is indicative of the results from the other General Radio dosimeter which was tested.

The Bruel and Kjaer dosimeters gave very good results. As can be seen for meter #4, all points are within tolerance with the indicated noise dose being much closer to the nominal noise dose than the General Radio dosimeter.

Both dosimeters show a general improvement in indicated noise dose as the frequency of the sound signal increases. This trend is most obvious for the B&K dosimeter.

Basically, then, both dosimeters perform within the limits of the ANSI Type 2 A-weighting tolerances, with the B&K

dosimeters exhibiting much closer indication of the nominal noise dose. Both dosimeters indicate conservative noise doses for the wearer. That is, both dosimeters tend to overestimate the noise dose received by the wearer. The Bruel and Kjaer dosimeters indicate a definite dependence of indicated noise dose on signal frequency, the indicated noise dose improving with increase in frequency (at least up to 800 Hz). This effect is also discernible in the General Radio dosimeters but to a far lesser extent.

The results for the three B&K ISO dosimeters were essentially the same as those of the B&K OSHA dosimeters.

5.1.2.2 Constant Frequency-Increasing Sound Level

The results of the tests performed with constant frequency and time duration but increasing sound pressure levels are shown in Figure (10). Once again the results are shown only for meters #4 and #7 since the results for the other OSHA dosimeters were similar.

The tests were performed at different sound levels for constant 24 minute durations. The frequency of the sound was 200 Hz. The tolerances allowed by the ANSI SI.4-1971 Type 2 tolerances are also shown.

The dosimeters are within the allowable tolerances with the General Radio dosimeter "sitting" on the upper tolerance limit and the B&K dosimeter indicating values very close to nominal. Neither dosimeter shows any significant variation of indicated noise dose, relative to nominal noise dose, with increasing sound pressure level.

5.1.2.3 Intermittent Noise

Figure (11) shows the results of the intermittent noise tests.

There seems to be no significant variation in relative percentage noise dose due to changes in duty cycle. However for a duty cycle of 50%, both dosimeters seem to show the beginning of an increasing variation from the nominal.level. Figure (12) shows this in terms of relative level in dBA. The "relative level" is defined as the level indicated by the dosimeters (Leq) relative to the actual tone burst level used. These findings would be consistent with the results of studies by Wilkerson (56) who showed variations of from 1 to 5 dBA at 50% duty cycle increasing to 5 to 12 dBA at 20% duty cycle, depending on the dosimeter tested. Of course the variation shown in Figure (12) is small and would require a number of points for lower duty cycles to substantiate any variation. Unfortunately, due to the lack of immediately available equipment to perform such tests, no lower duty cycles were obtained.

Similarly no significant variation of relative percentage noise dose with duty cycle was noted for the B&K ISO dosimeters for duty cycles down to 50%.

5.1.2.4 Cold Tests

For durations of up to 20 hours at 0°C, no effect was noted on the noise dose indicated by the General Radio dosimeters.

The effect on the noise dose indicated by the B&K dosimeters was insignificant. However the battery life of these dosimeters was greatly reduced. A functional life as short as 5 hours was observed at 0°C. As a precaution, it was decided that all dosimeters should be kept as warm as possible during winter runs.

5.1.2.5 Other Factors Affecting the Use of the Dosimeters

The B&K dosimeters were found to be the easiest and fastest to calibrate. In addition their read-out could be obtained from an integral display which did not require a separate indicator unit as did the G.R. dosimeters. Also, the state of the batteries of the B&K dosimeters could be ascertained at the flick of a switch. For the G.R. dosimeters battery indication required mounting the dosimeter on the indicator unit.

The B&K units seem to be the more rugged and reliable of the two dosimeters. Not one of the six has been returned for repair in the year and a half period since they were first received. In the same time interval two of the three General Radio dosimeters have been back to the factory for repair.

In the area of wearer comfort both dosimeters are about equal from a size and weight point of view. However, the B&K dosimeters utilize a 1/2" microphone which is quite large relative to the microphone used by the G.R. dosimeter. A number of subjects complained about the discomfort of the B&K microphone when it was mounted at the ear. This was especially true of subjects wearing crash helmets.

5.2 Body Baffle Effects

5.2.1 Procedure

5.2.1.1 Basic Considerations

Tests were run to determine the extent of baffle effects on sound pressure level monitoring by microphones mounted near the body.

It was desired to find a position which produced effects as small as possible and which were not highly dependent on body orientation to the sound. This is obviously of some importance in personal noise dosimetry since, in this case, the microphone is mounted on the person. Choosing a position which experiences extreme baffle effects and variability with orientation could introduce considerable error into the noise dose indicated. Since noise dose standards are based on levels which are monitored at the position of the subjects head with the subject absent, the monitoring position chosen for body mounting of a microphone would, ideally, produce sound levels which varied as little as possible from the "no-subject" sound level.

5.2.1.2 Test Set-Up

Considering the fact that operators of snowmobiles and motorcycles most often operate in semi free-field conditions, it was decided that all measurements would be taken under such conditions. Therefore, the test site chosen was a large, open, level field. The field was grass covered with the nearest structure over three hundred feet away. The ambient noise level was 57 dBA with peaks to 61 dBA.

Initial tests were run with male subjects but later a male mannequin was employed after the test sequence had shown definite correspondence between the results achieved with the male subjects and those of the mannequin. The use of the mannequin removed the problem of subject fatigue due to the requirement to stand perfectly still during a rather lengthy test sequence.

It was decided to use the ear bug to monitor the sound pressure levels at specific points on the subject's body.

5.2.1.3 Testing Sequence

A test sequence began by positioning the ear bug microphones on the subject. The positions used were at the left ear, the left collar tab and the left breast pocket. The sound pressure level at the test position was set at 80 dBA with the subject absent. This level was monitored using a calibrated B&K 4145 1" microphone in conjunction with a B&K 2619 preamplifier and B&K 2607 measuring amplifier.

The monitor microphone was positioned at the point which would be occupied by the subject's head, directly facing the sound source. The desired test frequency was generated by a B&K 1022 beat frequency oscillator which, in conjunction with the B&K 2706 power amplifier, drove a University Sound high fidelity speaker. A total of fourteen discrete frequencies, from 100 Hz to 5000 Hz, were used in a single test sequence.

When both the frequency and sound level had been properly adjusted, the monitor microphone was removed and the subject placed at the test position. The ear bugs were then turned on and the sound pressure levels at the chosen positions were recorded for a particular frequency. This procedure was repeated for each of the fourteen test frequencies. In addition, the tests were performed with the subject facing the noise source (0° incidence) and facing directly away from the noise source (180° incidence).

5.2.1.4 Noise Source Position

To determine the effect of the noise source position, two noise source locations were used, at a horizontal distance of 180 centimetres and 55 centimetres, respectively, from the vertical centre plane of the subject. At both positions the speaker was directed toward the head of the subject. The centre of the speaker was maintained at a height of 30 centimetres above the ground. Figure (13) shows the mannequin in the test position.

5.2.1.5 Clothing Effects

A number of different clothing combinations were used on the mannequin to determine the effect on the sound pressure levels sensed by the ear bug microphones. These clothing combinations were, (a) a light shirt, (b) a sweater and quilted ski jacket, (c) the ski jacket over 2.5 cm thick foam rubber pads, (d) a sweater and leather jacket, and (e) the leather jacket over the foam rubber pads. For all tests the mannequin wore a pair of wool pants.

5.2.1.6 Method of Analysis

The results of a test sequence were played back from the ear bugs through a B&K 2607 measuring amplifier into a B&K 2307 level recorder. The sound levels indicated on the level recorder were then corrected to account for the frequency response of the ear bugs. These corrected values are used in the following discussion of results.

5.2.2 Results and Discussion

5.2.2.1 Data Averaging and Scatter

The experimental data points shown in the figures of this section are the average of at least two and as many as four test sequences.

For frequencies of 1000 Hz and below the greatest total variation at any point was 5 dBA. This was experienced only twice. Generally the variation for repeated tests was 3 dBA or less with most showing no more than 2 dBA variation. The extreme variations for frequencies above 1000 Hz were much greater. At one point a 14 dBA range was experienced with values of 6 or 7 dBA not uncommon at the higher frequencies. These large variations were probably due to differences in the distance of microphone attachment from the body and other minor dimensional errors, since at higher frequencies these factors can be quite significant. However, since the noise produced by recreational vehicles is mostly governed by low frequency noise, the greater scatter at high frequencies was not considered to be of significance in this study. Thus, although data is shown for frequencies well above 1000 Hz, the actual comparison of results is generally based on the data for frequencies of 1000 Hz and less.

Finally it should be noted that although the data points are connected with a smooth line, this is not meant to represent the best fit curve through these points or any other experimentally or theoretically derived curve. The smooth curve is included only as an aid in following the trends indicated by the data points. In addition, the smooth curve is in keeping with the accepted method of data presentation in this field, as evidenced by such researchers as Sivian and O'Neil (61), Muller et. al. (62), Carlisle and Mundel (63) and Hanson (64).

5.3.2.2 Tests on Live Male Subjects and Mannequin

Figure (14) shows the results of a series of tests performed with three live male subjects and the mannequin for the "at ear" microphone position. The relative sound pressure level is defined as the increase or decrease in sound pressure level at the point of measurement, relative to the sound level existing at the monitor microphone position when the subject is absent.

These curves display the characteristics of free field baffle effects found by earlier researchers (61)(62).

It should be noted that the results for the mannequin are in good agreement with those of the live subjects. Similar agreement was found for the breast pocket and collar positions. Because of this correlation between the live subjects and the mannequin, it was felt that, for this study, valid results could be obtained by using the mannequin as the only test subject. Thus the remainder of the results detailed are for the mannequin only.

5.2.2.3 Different Monitoring Positions

The results shown in Figure (15) are for 0° incidence, the speaker at a distance of 180 centimetres, with the mannequin wearing a ski jacket and sweater. No significant difference is evident among the three monitoring positions used. Each of the positions would seem to be equally good (or bad) as a choice for a monitoring microphone. However, if we look at Figure (16) we see something very interesting.

For the breast pocket position, the sound levels sensed for 180° incidence are far different from those at 0° incidence. The body acts as a barrier to shield the ear bug microphone from the sound incident on the mannequin's back. The result is very much lower sound levels sensed at the breast pocket position.

The same results can be seen in Figure (17) for the collar position.

Figure (18), however, shows results far different than those for the breast pocket or collar. In this case, it is obvious that the change in incidence has little effect on the sound pressure levels monitored at the ear. Notice also that, for both incidences, the perturbations of relative sound pressure level about the zero level are generally small up to 1500 Hz. This means that the sound levels sensed at the ear closely approximate the levels which would be present at the same point in space in the absence of the subject. Thus the noise dose as measured at the ear would present a much more accurate representation of the noise dose of the subject as defined by existing standards.

All the above results are summarized in Figure (19). This permits an appreciation of the magnitude of the change due to incidence for the collar and breast pocket positions relative to the ear position.

5.2.2.4 Effects of Clothing

Since operators of motorcycles and snowmobiles often wear very different clothing, tests were performed to determine the effects of clothing changes. As mentioned earlier five types of clothing were used. Figure (20) shows the results of these tests for the ear position and 0° incidence. The vertical lines represent the total range of values at each frequency for the five types of clothing. The smooth curve intersects the vertical lines at the average value of the five clothing types.

First it should be noted that the smooth curve in this figure is essentially identical to the curves shown in Figure (18). In addition, the scatter in the values is small up to a frequency of about 3000 Hz. Above 3000 Hz the scatter becomes much larger, but this is to be expected. At the small wavelengths associated with the higher frequencies, the clothing worn can have a significant effect on the magnitude of the sound waves reflected from the subject. The result is a drastic change in the sound field associated with the higher frequencies. This effect is in addition to the effects of minor dimensional changes from test to test which can be significant at higher frequencies.

However, remembering the very minor contribution of sound frequencies much above 1000 Hz to the overall noise exposure of a snowmobile or motorcycle rider, it can be said with some confidence that the effect of clothing is small and can, in general, be ignored when considering its effect on the measured noise dose of recreational vehicle operators.

5.2.2.5 Effect of Source Position

Finally, Figure (21) shows the effect of changing the source position for "at ear" measurements. In this case little effect is noted up to frequencies of 1000 Hz. There does seem to be an effect at about 400 Hz but it is reasonably small and quite localized. Basically, the source position seems to have little effect on the sound pressure levels when measured at the ear for frequencies of 1000 Hz and less (the most important frequencies for recreational noise dose measurements).

5.3 Noise Attenuation Characteristics of Crash Helmets

5.3.1 Procedure

5.3.1.1 Basic Considerations

As mentioned in Section 3.3, little information is available on the noise attenuation characteristics of crash helmets. In an effort to better understand the effects of crash helmets on the noise dose incurred by recreational vehlicle operators who, by law, must wear helmets, it was decided that a study of limited scope should be undertaken.

Only one helmet brand was used in this test (Ski-Doo T'NT snowmobile helmets). The construction of all crash helmets is basically the same and little, if any, biasing of the general results is expected from this limitation. A total of four different helmet sizes (small, medium, large and X-large) were available for testing. In addition to the different helmet sizes, a snap-on peak and a full face visor were available for use with the helmets.

The helmets were worn by seven male volunteers and one fiberglass male model head called NIBS.

5.3.1.2 NIBS

NIBS was designed on the basis of normal male head dimensions. The head was hollow and therefore, during testing, it was stuffed with glass fibre and the access hole (at the base of the neck) was plugged with 3/4 inch plywood to prevent any internal reasonances from being generated. NIBS was mounted on a tripod equipped with a swivel plate which allowed rotation of the head about its vertical axis. This plate was marked off in ten degree intervals and NIBS could thus be positioned easily and repeatedly where desired. Figure (22) shows NIBS mounted on the tripod.

For comparison purposes it should be noted that Subjects 1 through 7 are the male volunteers, while NIBS is Subject 8.

5.3.1.3 Microphone Positioning

To monitor the sound levels, the subjects had an ear bug mounted at one ear and a B&K #4424 ISO standard noise dosimeter, operating in the accelerated mode, mounted at the other ear. Since NIBS had no ears, holes were drilled at the points normally occupied by the ear canals, to accept the ear bug and dosimeter microphones. See Figure (23).

5.3.1.4 Test Chamber - "Quiet Room"

All results detailed in this section were obtained in a 2.7 x 2.4 x 2.1 m. "quiet room" normally used for audiometric and human response time testing. The walls and ceiling of this room were covered with sound absorbing material while the floor was plywood covered with thick carpet. For frequencies from 200 Hz to above 2000 Hz the room permitted generation of highly directional sound fields with only small amplitude standing waves. One wall of the room had a glass viewing window which was covered with glass fibre during testing. The ambient noise level in the room with the door closed was about 35 dBA.

5.3.1.5 Test Sequence

Two types of tests were performed in an effort to evaluate the helmets' performance.

The first test was a constant sound level using (a) a single pure tone (500 Hz) and (b) broadband (pink) noise.

In the "a" part of this test a B&K 1022 beat frequency oscillator in combination with a B&K 2706 power amplifier was used to drive a University Sound high fidelity speaker at a frequency of 500 Hz. The sound level at the point to be occupied by the middle of the subject's head was monitored with a B&K 4145 1" microphone in conjunction with a B&K 2607 measuring amplifier. The sound level was adjusted to 93 dBA with the subject absent and the entrance door closed. The speaker was then switched off, the monitor microphone moved well out of the way, and the subject then entered the room and sat on a small stool. The speaker was at the subject's feet, but pointing at the centre of his head which was 1 metre distant. The door was shut, the subject turned on the ear bug and dosimeter, and the pure tone signal was started. After one minute the noise was turned off, the subject stopped the ear bug and then read out the dosimeter noise dose. When the noise dose was recorded the dosimeter was reset for the next run. This test was run for the subject with no helmet on, with helmet only, with helmet and peak and finally for helmet with visor. These tests were then repeated for the subject turned 180° from his original position.

The "b" part of this test sequence consisted of replacing the pure tone signal with a pink noise (equal energy per octave) signal. In this case the B&K 1405 noise generator was used to provide the broadband signal to the power amplifier and speaker. The procedure was as detailed for the type "a" test.

A second group of tests were performed to evaluate the effect of frequency on the noise transmission of the test helmets. This test was performed in a similar manner to that described above, except that eight constant level (93 dBA), discrete tones were used. The frequencies ranged from 200 Hz to 2000 Hz and were generated by the B&K 1022 beat frequency oscillator. This test sequence was performed for "no helmet" and "helmet only" conditions using Subject 1. The test was run only once and therefore there is no averaging of the data points.

5.3.2 Results and Discussion

5.3.2.1 Pure Tone and Braodband Noise

Table (1) summarizes the results of the constant sound level test for a 500 Hz pure tone while Table (2) presents the broadband noise results. The values shown are the sound levels at the ear as sensed by the ear bug and the dosimeter, relative to the level which existed at the centre of the subject's head with the subject absent. All values are in decibels.

The values obtained from the ear bug were frequency compensated prior to computing the relative levels. In the case of the dosimeter, the levels shown are based on the Leq value calculated from the noise dose indicated by the dosimeter.

There are blank spaces in the tables since each subject did not wear all the helmet sizes available. Generally each subject wore his "best fit" helmet along with helmets one size smaller and one size larger. The "best fit" helmet was the one which the subject would wear if given a choice. If the "best fit" helmet was a size small, then helmets one size and two sizes larger were worn. The "best fit" helmet of each subject is denoted by a black triangle in the upper left hand corner of the results listed under that particular helmet size.

It will also be noted that a number of dosimeter results are blank. In these cases the dosimeter indicated zero percentage noise dose. This indicates levels below 80 dBA, but no Leq value can be calculated and thus no relative level could be determined. As an indication, however, the reference level was 93 dBA and thus the reduction indicated by these blanks is at least 13 dBA.

The inclusion of the dosimeter results permits comparison with the values obtained from the ear bug. As can be seen from the tables, in many cases the correlation between the dosimeter and ear bug is exceptionally good. Unfortunately, there are also a number of cases where the results are exceptionally bad. The reason for the lack of agreement in particular cases is not totally clear. Certainly some variation in the noise field from one ear to the other is a possibility, but the magnitude of error in some cases would indicate this is not the sole factor involved.

The possibility that the orientation of the microphones on the ear is a factor seems good. The ear bug microphone is rather insensitive to orientation, but this is not the case for the dosimeter microphone.

The dosimeter microphone may have been preferentially oriented when the subject was putting on the test helmets. Thus the dosimeter microphone may have been sensitized to a particular orientation. As an example, note the results for Subject 5, medium helmet, in Table (1). The correlation of the results for frontal (0°) incidence is rather poor, yet the rear incidence results show remarkable correlation. Of course this is not always the case. Even when the subject is not wearing a helmet, and thus the microphone orientation factor should be very small, the results are sometimes quite different for dosimeter and ear bug. When (and if) this phenomenon is present cannot be determined absolutely from the results of this study.

A third factor that may come into play is the size of the microphones relative to the space available inside the helmet next to the ear.

The ear bug microphone is very small and fits easily into the available space. The dosimeter microphone on the other hand was quite large and often was pressed into the helmet's padding and into the subject's ear. This problem was noted many times by the subjects since it made wearing the helmets quite uncomfortable. The result of this "burrowing" would be a generally lower value of relative sound pressure level for the dosimeter results, due to the shielding of the microphone. In addition to the shielding effect of this "burrowing", the microphone also senses a changing sound field as it is pushed closer to the ear due to baffle and ear canal impedance effects. Many, but not all, of the poorer results show this type of effect.

Perhaps the best that can be said about the deviations found between the dosimeter and ear bug results is that they are a result of some combination of the above mentioned effects plus errors in subject positioning between tests, deviations in sound levels during testing, the natural deviations which occur in small sample test results, and other unknown effects. Additional work is presently being done to better define the effects at work and to determine which of the two systems is producing results which most accurately reflect the actual sound levels at the ear inside a crash helmet. Until more information is available, it is felt that the ear bug results are the more reliable under the conditions, and it is these results which will be discussed in further detail.

Figure (24) and Figure (25) show graphically the results tabulated in Tables (1) and (2), respectively, for the medium helmet and each subject. It is quite obvious that the results for a particular subject are generally quite different from those obtained for any other subject.

Since we are particularly interested in the effect which the helmets have on the sound levels at the subject's ear, it is perhaps more valuable to present the data in a manner which more directly indicates this effect. Therefore Table (3) and Table (4) summarize the results of the single pure tone and broadband noise tests respectively, with the data expressed as the sound pressure level sensed by the ear bug with the helmet on, relative to the level sensed by the ear bug with the helmet off. In this manner the effect of the helmet itself can be better determined. Of course it is realized that there are some coupling effects for the head-helmet combination which are not purely additive and thus cannot be effectively separated in this manner, but it is felt that the results obtained in this manner will definitely reflect the general trends which exist.

Figure (26) shows graphically the results for the subjects wearing the medium helmet. These results are indicative of the results for the other helmet sizes. As before, the results for each subject are basically unique. However, a rather interesting trend is noticeable. The relative sound pressure levels for the broadband noise are consistently low relative to the pure tone values. That is, the "transmission loss" (using a rather loose definition of the term) is generally greater for the broadband noise. This is not unexpected. If we remember that pink noise contains equal energy per octave and that higher frequency sound energy is very rapidly absorbed (and thus transmission loss is greater) by almost any material, we would expect, for broadband noise, a smaller amount of energy to pass through the helmet than would be the case for a 500 Hz pure tone which, with its relatively long wavelength, "sees" the helmet as a much less formidable barrier. Also, the smallest "leaks" around the sealing perimeter of the helmet provide extremely good access points for low frequency sound.

5.3.2.2 Effect of Helmet Size

Figure (27) shows the effect of helmet size on the relative sound pressure level for Subject 2. The obvious trend for the pure tone is less reduction in the sound level reaching the ear as the helmet size increases. This trend is also present for the broadband noise but to a much lesser degree. The same trends are evident for all the other subjects, except one, but are not as pronounced as those of Subject 2. As always, when working with data for individuals, certain results tend to be completely counter to trends established by the group. Subject 6, for the pure tone tests, shows results exactly opposite those detailed above. This serves to point out the basically individualistic nature of noise dose and the danger of blindly applying overall trends to particular individuals.

It should be noted that the "best fit" helmet for Subject 2 was the large helmet. Thus the helmet which is most comfortable for the wearer, and thus the one that is normally worn, is not the best helmet from a noise reduction point of view.

5.3.2.3 Effect of Peak and Visor

The reason for utilizing the snap-on peak and visor during the testing was to determine if they had an effect on the sound level produced at the subject's ear.

In the case of the peak, the results tend to indicate little if any consistent difference between the "helmet only" and "helmet with peak" conditions. However in the case of the helmet with visor there seems to be a rather consistent increase in noise level of about 2 dBA relative to the "helmet only" level. This may well be due to the reverberation effect produced by completely enclosing the head.

5.3.2.4 Average for All Subjects

Figure (28) shows graphically the average values of the relative sound pressure level for all eight subjects when exposed to pure tone and broadband noise, respectively. The pure tone results follow the trend shown in Figure (27) for Subect #2. The broadband results show a basically "neutral" effect for relative sound pressure level versus helmet size. The size of the drop of relative sound pressure level for the broadband noise is generally much larger than that indicated for the pure tone.

Thus we can expect poorer sound protection from crash helmets for sounds which have dominant low frequency pure tone characteristics than for those which are broadband in nature. On the average, the results of these tests for frontal sound incidence show levels of helmet attenuation ranging from 2 dBA to 6 dBA for the 500 Hz pure tone and from 5 dBA to 8 dBA for the broadband noise.

5.3.2.5 Rear Incidence

Interestingly, the sound attenuation characteristics of the helmets tested tend, on the average, to be poorer for the rear incidence condition. This may well be due to the design of the helmets. Although the area around the side of the face is well padded and generally seals snugly against the head, the section across the back of the neck is lightly padded and does not fit tightly at the base of the neck (for obvious comfort and safety reasons). Thus the sound has a kind of open channel at the back of the helmet. The result is more sound energy reaching the ears when the sound is incident from the rear. Thus for rear incidence the sound attenuation ranges from a slight amplification to an attentuation of about 4 dBA for the single pure tone noise, and from 5 dBA to 7 dBA for the broadband noise.

5.3.2.6 Effect of Frequency

Figure (29) shows the results of the test performed to evaluate the effect of the sound frequency on the attenuation characteristics of the crash helmets. The smooth lines shown are only used to accent the trends indicated by the data points. The now familar body baffle effects are evident.

The data shows slightly more spread than would be expected from the results of Section 5.2.2, however this is probably due to the fact that the data points shown are for one test only, and are not the average of a number of tests. In spite of this, certain trends are clear.

If we take the values obtained while the subject was wearing the helmet and subtract from them the values found when the subject was wearing no helmet, for each frequency, we will get effective helmet transmission loss versus frequency. Figure (30) shows this plot. Once again the lines indicate trends only.

For low frequencies the helmet attentuation stays effectively constant up to about 600 Hz for both front and rear incidence. Above 600 Hz the transmission loss of the helmet begins to drop off rather rapdily with increasing frequency.

5.4 Noise Expsoure of Snowmobile and Motorcycle Operators

5.4.1 Proceudre

5.4.1.1 Test Set-Up

Generally, the noise dose of the vehicle operators was measured using a combination of the B&K dosimeters (either ISO or OSHA standard), the G.R. dosimeters (OSHA standard only) or the ear bugs (ISO and OSHA simultaneously). The microphones of any two of the above instruments were mounted at the operator's ears, under their helmets. In the case of the snowmobile riders, the instruments were kept as close to the operator's body as possible in an effort to keep them relatively warm. The motorcycle operators usually clipped the instruments to their belt. For the most part, the operators were the owners of the vehicles being tested, although in the case of the motorcycles, one experienced rider was used to test a number of vehicles procured from various sources.

A normal test run consisted of a particular time period during which the operator performed normal manoeuvres over typical operating terrain. For snowmobiles this usually meant cross-country or trail riding under winter conditions (ground snow covered) while for motorcycles the runs were lumped into either city or highway driving on dry pavement. The time period used for the motorcycle tests was 50 minutes while that of the snowmobiles varied from 50 minutes to 5 1/2 hours. The snowmobiles tested were designated by letters while the motorcycles were designated by numbers. Table (5) and Table (6) list the model year, type, and displacement for each of the snowmobiles and motorcycles tested.

5.4.1.2 Dosimeter Noise Dose and Leq

When using the dosimeters, the noise dose was read directly from the display of the units themselves. The Leq value could then be easily determined, knowing the time of exposure, by using either monographs supplied with the instruments or the equations detailed in Sections 2.16 and 2.17.

5.4.1.3 Ear Bug Noise Dose and Leq

Determining the noise dose from the ear bug tapes was slightly more involved. In this case the results were played back through the B&K Model 125 spectrum shaper, to correct the ear bug's frequency response, and from there into the B&K 2307 graphic level recorder to which the B&K 4420 statistical distribution analyzer had been attached. This permitted the signal to be broken up into twelve discrete level ranges or channels. The statistical analyzer would automatically count, every .1 second, the number of times it found the level to be in any particular channel. The writing speed of the level recorder was adjusted to correspond to the "slow" response of a sound level meter. This is the same response used by the dosimeters.

Figure (31) shows a typical output divided into the twelve channels and their corresponding ranges. Basically this figure shows ten channels which cover 2.5 dBA ranges. The other two channels cover the greater than and less than ranges at the extremes of the paper width. Generally the signal level was adjusted to keep the signal out of these "greater than" or "less than" ranges since picking an average or mid-point value to represent them was rather arbitrary. If a signal did fall into these limit ranges the "mid-point" was taken as being 2.5 dBA above or below the upper or lower limit levels, respectively.

The expression for noise dose was given by equation (2.1) as,

$$D = [\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n}] \times 100 \qquad (2.1)$$

Since the analyzer automatically determines the lengths of time spent at a particular level (number of counts in a particular channel times the counting time of .1 second) the actual time of exposure to a given level (assumed to be the mid-point of the channel range) is easily determined. To determine the allowable time for 100% exposure under particular standards (ISO or OSHA) for each mid-point level, they need only be read off a graph such as Figure (1). With these values determined the calculation of the noise dose becomes very simple.

The general expression for Leq is given by equation (2,6) as,

$$Leq = 10 \log_{10} [\frac{1}{T} \int_{o}^{T} (\frac{p(t)}{p_o})^2 dt] \quad (2.6)$$

This can be approximated for our purposes by,

$$Leq = 10 \log_{10} [\frac{1}{T} \sum_{j=1}^{12} (\frac{p_j}{p_o})^2 \times t_j] \quad (5.1)$$

where the subscript 'j' refers to the values for each of the twelve channels.

Since by definition,

$$L_j = 10 \log_{10} (\frac{p_j}{p_o})^2 \quad (5.2)$$

thus,

$$\text{antilog} [\frac{L_j}{10}] = (\frac{p_j}{p_o})^2 \quad (5.3)$$

or,

$$10^{(\frac{L_j}{10})} = (\frac{p_j}{p_o})^2 \quad (5.4)$$

Thus equation (5.1) may be rewritten as,

$$Leq = 10 \log_{10} [\frac{1}{T} \sum_{j=1}^{12} 10^{(\frac{L_j}{10})} \times t_j] \quad (5.5)$$

The Leq value is now easily determined since values of t_j and L_j are known. This method has been found to produce results which are generally within ± 1 dBA of a known Leq value.

It is worth noting that the Leq values calculated from the dosimeter noise dose, and the Leq calculated for the ear bug results are not necessarily directly comparable. This is due to the presence of the dosimeter cut-off value (e.g. 90 dBA for OSHA criterion).

The differences introduced into the Leq values because of this are quite small if the levels monitored generally remain above the integration inhibition (cut-off) level. The differences normally become significant only when the sound level being monitored "hovers" around the integration "cut-off" value of the dosimeter in use.

Thus for the work in this study, the values of Leq should be nearly the same, since the levels monitored are generally above the integration inhibition level. For a more detailed explanation of this problem see Appendix C.

5.4.2. Results and Discussion

5.4.2.1 Snowmobiles

A summary of the test results is shown in Table (7). To present all the noise dose data on an equal time base, the noise dose has been scaled to the equivalent eight hour value (represented by "ISO_8" or "$OSHA_8$"). This permits comparison between values and also gives an indication of the noise dose incurred by the snowmobile operators relative to the allowable limits for noise dose of factory workers. Those figures which have a "mod" under them have been obtained using one of the dosimeters modified as detailed in Section 2.17.

Many of the noise dose values are very high. Generally they indicate an average rate of noise dose accumulation two to four times greater than would be allowed for a factory worker under presently existing legislation.

The Leq values cluster around 100 dBA. This would mean an allowable exposure limit of 2 hours per day based on the OSHA criterion (less than 1 hour for ISO criterion). When we consider that many persons operate their snowmobiles for a few hours after work, where they may already have recieved 100% of their allowable daily noise dose, the potential for hearing damage is obvious.

Figures (32), (33) and (34) show histograms of the noise level recorded by the ear bug during test runs of Vehicles A, B and C respectively. It is obvious from the information shown on these figures that the noise generating characteristics of various snowmobiles can be quite different. The range of Leq is from 92 dBA to 103 dBA.

Figures (35),(36) show real time analysis of the noise at the operator's ears as recorded by the ear bug during a test run of Vehicle A. The results shown are typical of snowmobile noise. As expected, the noise is basically composed of low frequency pure tone components. It should be noted that the high levels of exposure are dominated by these discrete components and thus by the response of the measuring instruments to these low frequency pure tone components. These discrete components are the result of the exhaust noise and to a lesser extent the engine noise. These low frequency components are difficult to attenuate and will probably require considerable effort in both muffler and helmet design if significant reduction is to be achieved.

5.4.2.2 Motorcycles

Table (8) provides a summary of the test results for the motorcycles.

The most obvious result is the generally lower Leq values for the motorcycles relative to the previously detailed snowmobile values.

Secondly the values of Leq obtained for city runs are much lower, on the average, than those noted during highway runs. This is as expected. During high speed highway runs wind noise would be expected to make a significant contributuion to the noise generated at the operator's ears thus increasing the overall noise level sensed. Also, for city driving the highest levels obtained are much more intermittent in nature and the maximum noise levels are generally lower than those generated at higher engine speed operation. The combination of these factors results in much higher Leq's for highway driving relative to those for city driving.

Figure (37) and (38) show narrow band analyses of noise recorded at the operator's ear for a low speed (~30 mph) test. Pure tone, low frequency components are predominant. This is characteristic of exhaust and engine generated noise at normal and higher engine rpm. Figures (39) and (40) show the same type of analyses for a high speed (~55 mph) test run. Now the noise generated is basically broadband in nature with the previously predominant pure tones buried in this typical wind generated (turbulent) noise.

Although the noise exposure of motorcycle riders seems to be lower than for snowmobile operators, it should not be considered that the risk of signficiant hearing damage is also low. Many of the highway runs generated Leq's very close to 100 dBA. This is a significant enough magnitude to cause concern for hearing damage. The existing OSHA criterion for industry would allow this exposure to continue for only 2 hours in an eight hour day. The ISO criterion would permit less than 1 hour exposure. These exposure times could easily be exceeded on a trip of even moderate distance. The potential for hearing damage most certainly exists.

Figures (41) through (54) show histograms of the "at ear" noise levels for a number of different motorcycles under highway and city driving conditions. It is obvious that the characteristics of noise generation for each motorcycle can be quite different. However, some basic factors, other than the vehicle itself, have been found to affect the noise levels produced at the operator's ear.

Figure (55) shows the results of three tests run with the same vehicle and operator under three different driving conditions. As the average speed increases from about 25 mph in the city to 55 mph on the highway, the Leq rises from 90 dBA to 100 dBA. It is at about 45 mph that wind noise begins to become significant. It is obvious that the type of driving can greatly influence the noise exposure of the operator. Figure (56) presents the same data in a slightly different form. In this case the cumulative distribution of the noise levels are shown. At a speed of 55 mph, fully 50% of the test time was spent at noise levels greater than or equal to 101 dBA, while for city driving the figure was only 90 dBA.

The effectiveness of a face visor in reducing the at ear noise level of the operators was also examined. In this case an operator rode the same motorcylce under identical conditions except that for one run he wore a visor and for the other he did not. The results are shown in Figure (57). The visor produced a 2 dBA reduction in the Leq value. This is in spite of the fact that we might expect some amplification of the directly radiated noise because of the reverberation effect present when using the visor. This amplification effect was found during the static tests of the helmet-visor combination. Once again, it is probably present but in the dynamic situation (wind present) the visor greatly improves the streamlining of the operator's head. This in turn reduces the turbulent wind noise generation. The reduction in wind noise is sufficient to produce an overall drop of the sound level in spite of the slight amplification effect of the visor-helmet combination. The visor used for this test did not fit snugly to the helmet and thus may not have reached the full turbulent noise reduction possibilities of more closely fitting visors. Figures (58) and (59) show some very significant results. In this case two operators used a test course at the same speed. Each operator had a different motorcycle. The first subject left to cover the test course 30 seconds before the second subject was allowed to begin the course. The test course was therefore covered by the operators at approximately the same time, thus removing any significant atmospheric or traffic variations. When the operators returned they were told to exchange motorcycles and cover the test course as before. The operators used the same gears and cruised at the same speeds when operating a particular motorcycle. Thus each motorcycle was driven under the same conditions for both parts of the test; only the operators differed.

Assuming that one of the motorcycles is at least slightly "noisier" than the other, then it would also be assumed that the operator riding the noisier motorcycle during each test segment would receive the higher noise dose. Thus we would expect one of the subjects to exhibit a higher Leq than the other subject for one test segment, and a lower Leq for the other segment.

Interestingly enough this does not happen. In fact

Subject 1 shows the higher Leq for both test segments. Thus the noise expsoure seems to depend to a great extent on the subject. It would seem that the body shape, individual's riding posture, and other characteristic factors enter into the final noise dose received by the operators. Certainly these factors could affect both the turbulent wind noise generation and also the relative obstruction of the path of directly radiated noise from the motorcycle.

Thus if motorcycles were ranked from "noisiest" to "quietest" using pass-by, stationary run-up, or other test means, and one subject rode a noisy motorcycle while another rode a quieter motorcycle, the person riding the noisier motorcyle would not necessarily receive the higher noise dose. This fact therefore has far reaching consequences for noise rating programs when attempting to relate a vehicle noise rating to the actual noise exposure of the operator. Much additional work needs to be done in this area to confirm this effect and determine its magnitude in a large sample study.

CHAPTER VI

CONCLUSIONS

(a) Noise Dosimeter Performance

(1) The integration performance of both the B&K and G.R. dosimeters tested falls within the limits allowed by ANSI SI.4-1971 Type 2 A-weighting tolerances. The B&K dosimeters give values of noise dose much closer to the nominal value than do the G.R. dosimeters, which tend to "sit" on the upper tolerance limit.

(2) Neither group of dosimeters show any significant dependence of noise dose error on incident sound level or duty cycle (down to 50% duty cycle).

(3) The B&K dosimeter performance improves slightly with the increase in incident sound frequency (at least up to 800 Hz). The G.R. dosimeters show little, if any, improvement with increasing frequency.

(4) The B&K dosimeters are easier to calibrate and operate, and are more reliable than the G.R. dosimeters. These advantages take on particular

significance in field applications, especially during the winter. The G.R. dosimeters are slightly more comfortable for the subject to use when the microphone is mounted at the ear.

(b) Body Baffle Effects

(1) The noise expoeure of a recreational vehicle operator depends basically upon the noise to which his hearing organs are subjected. Thus noise measurement at any position other than the ears is justified only if substantially the same sound conditions exist there as at the ears. Since the vehicle noise is dominated by discrete low frequency components, the microphone positions at the shirt collar and breast pocket can produce readings signficantly different than those at the ears. They are therefore not acceptable for determining the noise exposure of the vehicle operator. It is therefore concluded that the "at ear" position is the only acceptable microphone location for personal noise dose measurements of recreational vehicle operators.

(c) Noise Attenuation Characteristics of Crash Helmets

(1) The transmission loss through the helmets tested is generally greater for broadband noise than for pure tone noise of the same incident sound pressure

level.

(2) Helmet size has some effect on the sound transmission loss for a low frequency pure tone sound (transmission loss increases for tighter helmet fits) while little effect is noted for broadband noise.

(3) The "best-fit" helmet is not always the best helmet for sound attenuation.

(4) For the static case (no wind present), the addition of a face visor tends to increase the sound level at the subject's ears by about 2 dBA.

(5) The helmets tested show generally poorer sound attentuation when the sound is incident from the rear.

(6) For low frequencies, up to about 600 Hz, the helmet attenuation stays effectively constant and very small in magnitude. Above about 600 Hz the helmet attenuation increases rapidly. It is concluded that this condition results from a combination of transmission loss frequency characteristics and leakage from low frequency sound waves.

(d) Noise Exposure of Snowmobile and Motorcycle Operators

(1) Snowmobile operators are exposed to very high levels of noise which, particularly when combined with possible occupational noise exposure, produce significant

potential for hearing damage.

(2) The noise exposure of motorcycle operators is generally lower than that for snowmobile operators, but is still of sufficient magnitude to cause concern, especially at highway speeds.

(3) Wearing a visor under "dynamic" conditions (wind present) provides a signficiant noise reduction at the motorcycle operator's ears.

(4) The noise exposure of the operator does not depend solely on the motorcyle's noise generating capability but also on characteristics unique to the individual operators.

(5) For both motorcycles and snowmobiles the noise impinging on the operator's ears is basically low frequency, discrete pure tone in nature. Further reduction of this type of noise from present levels will require not only exhaust muffler and engine improvements, but also the use of helmets which are designed specifically to provide increased noise protection.

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CHAPTER VII

RECOMMENDATIONS

1) Additional work should be done to identify the factors which affect noise dosimeter readings when the monitor microphone is mounted at the ear under crash helmets.
2) Further study should be undertaken to determine, for a relatively large sample, the effects on noise dose of characteristics unique to individual vehicle operators such as body size, riding posture etc.
3) Larger sample studies should be undertaken to determine typical noise exposures of snowmobile and motorcycle operators under normal operating conditions for both early and late model vehicles.
4) Studies should be performed to determine quantitatively the effect of wind generated noise on the noise dose received by recreational vehicle operators under normal operating conditions.
5) Helmet attenuation characteristics should be further investigated with improved noise reduction capability as a primary goal.
6) Work should be undertaken to determine the effects on people and instruments of exposure to low frequency, discrete pure tone noise.

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APPENDIX A

Equivalence of Noise Dose Expressions

The following example applies equally well to the OSHA and ISO criteria. In this case the OSHA standard is used. The procedure for the ISO criterion is identical.

Noise dose is specified as,

$$D = \left[\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n}\right] \times 100 \qquad \text{(A1)}$$

The values of T_1, T_2, ... T_n are obtained from,

$$T_i = \frac{8}{\left(\frac{L_i - 90}{5}\right)} \qquad i = 1, 2, \ldots n \qquad \text{(A2)}$$

for each value of L_i.

For continuous noise dose monitoring the expression used is,

$$D = 100 \int_0^{T/8} \left(\frac{p(t)}{.632}\right)^{1.2} dt \qquad \text{(A3)}$$

Now the equation (A1) may be rewritten as,

$$D = 100 \times \left[\sum_{i=1}^{n} \frac{C_i}{T_i}\right] \qquad \text{(A4)}$$

Using equation (A2) in (A4) we have,

$$D = 100 \times \left[\sum_{i=1}^{n} \frac{C_i}{8} \, 2^{\left(\frac{L_i - 90}{5}\right)} \right] \qquad \text{(A5)}$$

But C_i is the actual time duration at any sound pressure level and can thus be written with the symbol t_i.

Thus,

$$D = 100 \times \left[\sum_{i=1}^{n} \frac{t_i}{8} \, 2^{\left(\frac{L_i - 90}{5}\right)} \right] \qquad \text{(A6)}$$

or,

$$D = \frac{100}{8} \left[\sum_{i=1}^{n} t_i \times 2^{\left(\frac{L_i - 90}{5}\right)} \right] \qquad \text{(A7)}$$

Now, for continuous monitoring of noise dose we may write equation (A7) as,

$$D = \frac{100}{8} \times \int_0^T 2^{\left(\frac{L_i - 90}{5}\right)} \, dt \qquad \text{(A8)}$$

This can be rewritten,

$$D = 100 \times \int_0^{T/8} 2^{\left(\frac{L_i - 90}{5}\right)} \, dt \qquad \text{(A9)}$$

Comparing equations (A9) and (A3) for equivalence,

$$2^{\left(\frac{L_i - 90}{5}\right)} \equiv \left(\frac{p(t)}{.632}\right)^{1.2}$$

Letting

$$2^{\left(\frac{L_i - 90}{5}\right)} = \beta \tag{A10}$$

$$\left(\frac{p(t)}{.632}\right)^{1.2} = \psi \tag{A11}$$

Taking logs of both sides we have,

$$\log \beta = \frac{L_i - 90}{5} \times \log 2 \tag{A12}$$

$$\log \psi = 1.2 \log \frac{p(t)}{.632} \tag{A13}$$

Equation (A12) may be rewritten,

$$\log \beta = \left[10 \log \left(\frac{p(t)}{p_o}\right)^2 - 10 \log \left(\frac{.632}{p_o}\right)^2\right] \times \frac{\log 2}{5}$$

$$= \frac{20 \log 2}{5} \times \log \left(\frac{p(t)}{.632}\right)$$

$$= 1.2 \log \left(\frac{p(t)}{.632}\right) \tag{A14}$$

Comparing equations (A13) and (A14) it is obvious that $\beta = \psi$ and thus equations (A1) and (A3) are equivalent.

APPENDIX B

Expressions for Leq in Terms of Noise Dose and Time Duration of Measurements

Consider the general expression for Leq,

$$\mathrm{Leq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_o}\right)^2 dt\right] \tag{B1}$$

where $p_o = 2 \times 10^{-5}\ \mathrm{N/m^2}$

Thus,

$$\mathrm{Leq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{2\times10^{-5}}\right)^2 dt\right] \tag{B2}$$

For the case of a dosimeter using the ISO criterion we have,

$$D = 100 \int_0^{T/8} \left(\frac{p(t)}{.632}\right)^2 dt \tag{B3}$$

as detailed in Section 2.15.

Dividing equation (B3) by 100 we have,

$$\frac{D}{100} = \int_0^{T/8} \left(\frac{p(t)}{.632}\right)^2 dt \tag{B4}$$

Next divide by T/8 to give,

$$\frac{D}{100} \times \frac{8}{T} = \frac{8}{T} \int_{o}^{T/8} \left(\frac{p(t)}{.632}\right)^2 dt \qquad \text{(B5)}$$

Considering a general time period and thus removing the eight hour normalization from the time duration limits we have,

$$\frac{D}{100} \times \frac{8}{T} = \frac{8}{T} \times \frac{1}{8} \int_{o}^{T} \left(\frac{p(t)}{.632}\right)^2 dt \qquad \text{(B6)}$$

Applying the factor $\left(\frac{.632}{2\text{x}10^{-5}}\right)^2$ to both sides of equation (B6) gives,

$$\frac{D}{100} \times \frac{8}{T} \times \left(\frac{.632}{2\text{x}10^{-5}}\right)^2 = \frac{1}{T} \int_{o}^{T} \left(\frac{p(t)}{2\text{x}10^{-5}}\right)^2 dt \qquad \text{(B7)}$$

Taking the logrithms of both sides and multiplying through by 10 gives,

$$10 \log_{10} \left[\frac{D}{100} \times \frac{8}{T} \times \left(\frac{.632}{2\text{x}10^{-5}}\right)^2\right] = 10 \log_{10} \left[\frac{1}{T} \int_{o}^{T} \left(\frac{p(t)}{2\text{x}10^{-5}}\right)^2 dt\right] \qquad \text{(B8)}$$

The right hand side of equation (B8) is obviously Leq. Therefore,

$$\text{Leq} \doteq 10 \log_{10} \left[\frac{D}{T} \times 79{,}884{,}800\right] \qquad \text{(B9)}$$

or simplifying,

$$\text{Leq} = 10 \log_{10} \left[\frac{D}{T}\right] + 79.02 \qquad \text{(B10)}$$

Thus we have Leq in terms of noise dose and the time duration of the measurement using the ISO dosimeter.

Similar procedures give the simplified expression,

$$Leq = 16.67 \log_{10} [\frac{D}{T}] + 71.73 \qquad \text{(B11)}$$

for the OSHA dosimeter.

The Leq would be rounded to the nearest 1 dBA after calculation from equations (B10) or (B11).

APPENDIX C

Dosimeter and Ear Bug Leq's

The purpose of this appendix is to point out possible discrepancies in Leq as calculated from typical commercial dosimeters and from the ear bug which was also used in this study.

First, it should be remembered that the dosimeters have a cut-off level below which they no longer integrate. In the case of the ISO dosimeters used in this study that limit is 80 dBA while for the OSHA dosimeters used it is 90 dBA.

Thus any sound energy below 80 dBA for the ISO dosimeter is "cut-off" and not included in the resultant Leq. Typically the result of this cut-off is rather small when comparing the Leq which is obtained from the dosimeter noise dose reading relative to the actual Leq. As an example, consider the case shown in Figure (C1) for an ISO dosimeter.

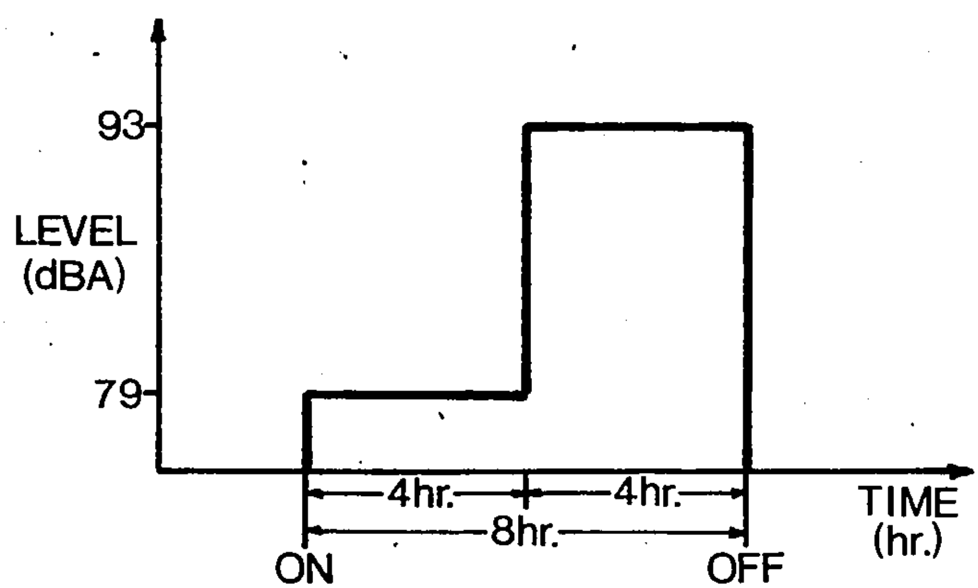

FIGURE (C1)

Since the 79 dBA level is below the cut-off level, the dosimeter ignores this signal during the four hour period it is present. When the signal jumps to 93 dBA the dosimeter begins to integrate. Since this is an ISO dosimeter the final dosimeter readout is 100% (93 dBA for 4 hours is 100% of the allowable exposure). Now, however, comes the problem. The actual measurement duration was 8 hours. Since in "real-life" we do not know the actual noise level as a function of time, we interpret the results as a noise dose of 100% for 8 hours or, according to the ISO criteria, an Leq of 90 dBA. The actual Leq is given by,

$$Leq = 10 \log_{10} \left[\frac{1}{T} \left(\left(10^{\frac{93}{10}} \times 4\right) + \left(10^{\frac{79}{10}} \times 4\right)\right)\right]$$

$$= 90.2 \text{ dBA}$$

The error is obviously quite small. This is usually the case both for ISO and OSHA dosimeters, although it would tend to be slightly higher for the OSHA dosimeters since, because of their higher cut-off level, they tend to "ignore" more of the sound energy than do the ISO dosimeters.

The error due to cut-off can, however, give rather large errors in Leq if the level being monitored tends to hover just under the cut-off and only intermittently rises above that level. In this case the result is a very small noise dose over a relatively long measurement duration (i.e. relative to the time the noise level was above the cut-off level) and thus a very low value for Leq as calculated from the dosimeter. The resulting error can then be quite high.

This case is not often encountered in actual noise dose measurements and generally speaking errors in Leq due to the cut-off are small and can often be ignored.

The ear bug Leq is essentially the "actual" Leq since it has no cut off level, except the limiting lower dynamic response of the tape recorder which can usually be made quite low relative to the average levels being monitored.

A second, and potentially more troublesome, problem arises since the ISO and OSHA dosimeters do not use the same time-intensity trading relationship.

The ISO dosimeters, which use the equal energy trading relationship of 3 dBA increase in level per halving of exposure time, can be shown to give the actual (energy equivalent) Leq value as defined by equation (2.6) with only a small error (usually) due to cut-off level.

The OSHA dosimeters, on the other hand, do not use the equal energy trading relationship but a 5 dBA increase in level per halving of exposure time relationship. The resultant Leq is thus not an energy equivalent sound pressure level, but an equivalent sound pressure level based on a 5 dBA level increase per halving of time trading relationship. The effect of this type of trading relationship can be seen from the following example.

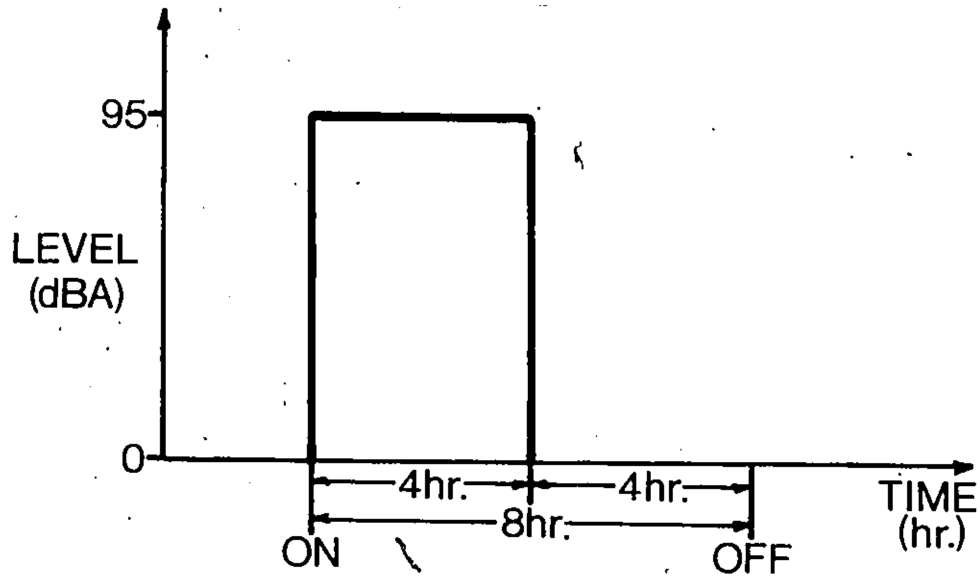

FIGURE (C2)

Suppose an OSHA dosimeter is exposed to the sound levels shown in Figure (C2). As in the previous example, we are not actually aware of the noise level variation experienced by the dosimeter. Thus, the result we see is a noise dose of 100% for an eight hour measurement duration. Therefore the Leq according to the OSHA dosimeter (i.e. the value read from typical conversion charts, tables or equation 2.8) is 90 dBA. However, the <u>energy equivalent</u> Leq is obviously,

$$\text{Leq} = 10 \log_{10} \left[\frac{1}{T} \left((10^{\frac{95}{10}} \times 4) + (10^{\frac{0}{10}} \times 4) \right) \right]$$

$$= 92 \text{ dBA}$$

Thus the OSHA dosimeter gives a different Leq than the energy equivalent Leq given by the ISO dosimeter and the ear bug.

The Leq as derived from an OSHA noise dosimeter can be significantly different (as much as 10 dBA or more) from the true value and can therefore lead to incorrect evaluations of the effects of noise. It should not be used in most applications. It is included in this study, however, to provide an indication of the levels determined when it is used in practice.

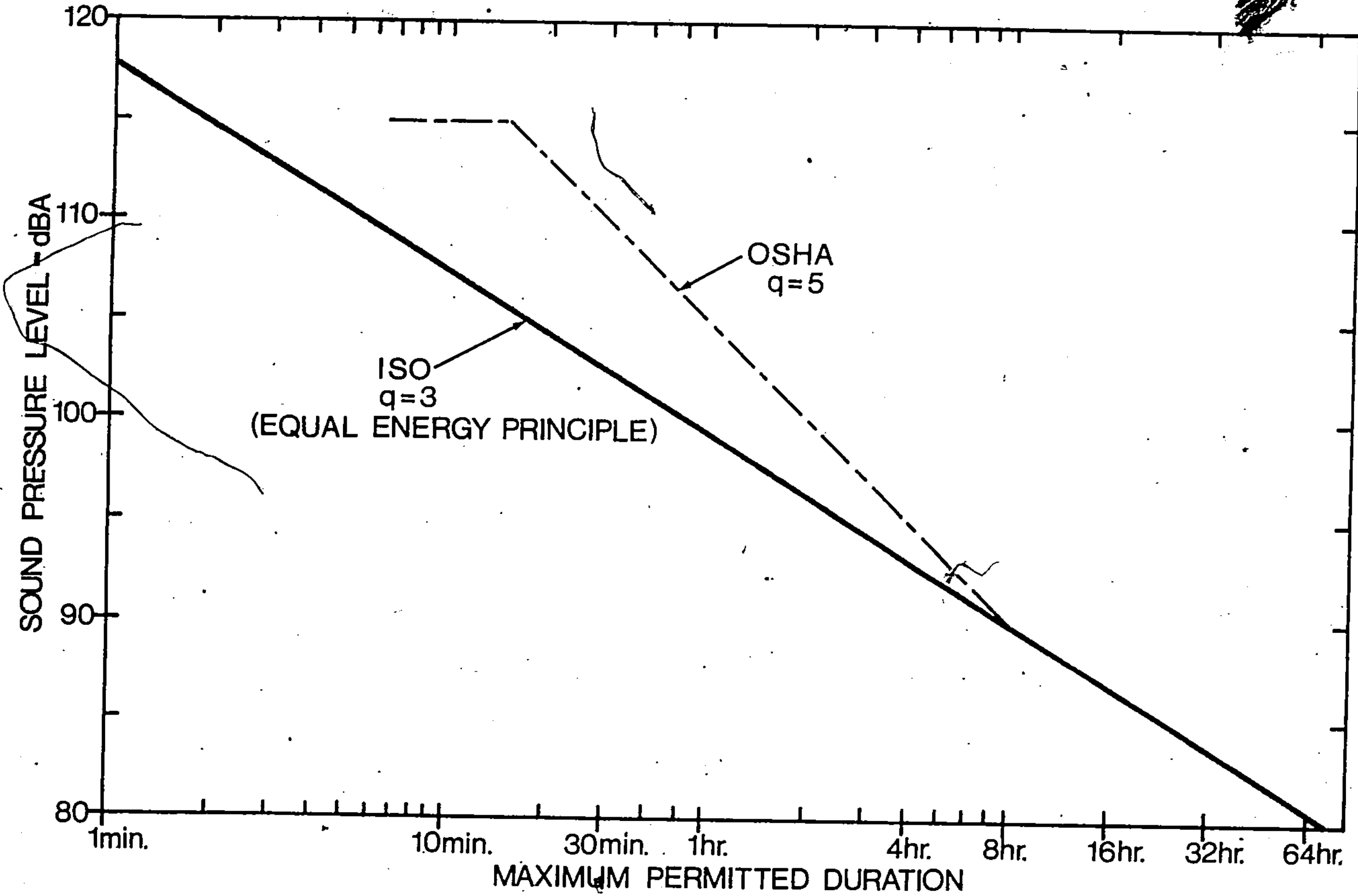

FIGURE 1 100% NOISE EXPOSURE FOR OSHA AND ISO CRITERIA

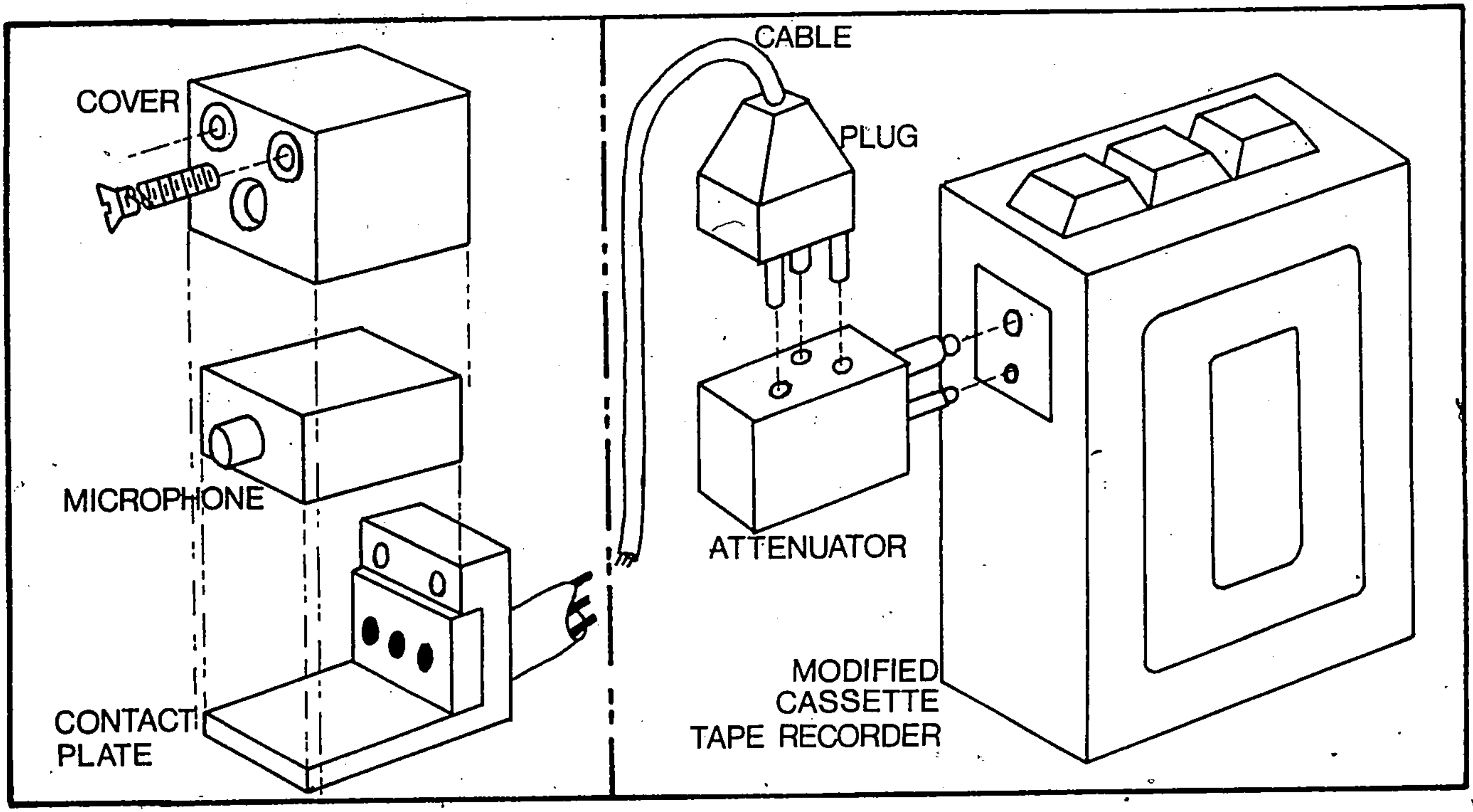

FIGURE 2 "EXPLODED" VIEW OF EAR BUG

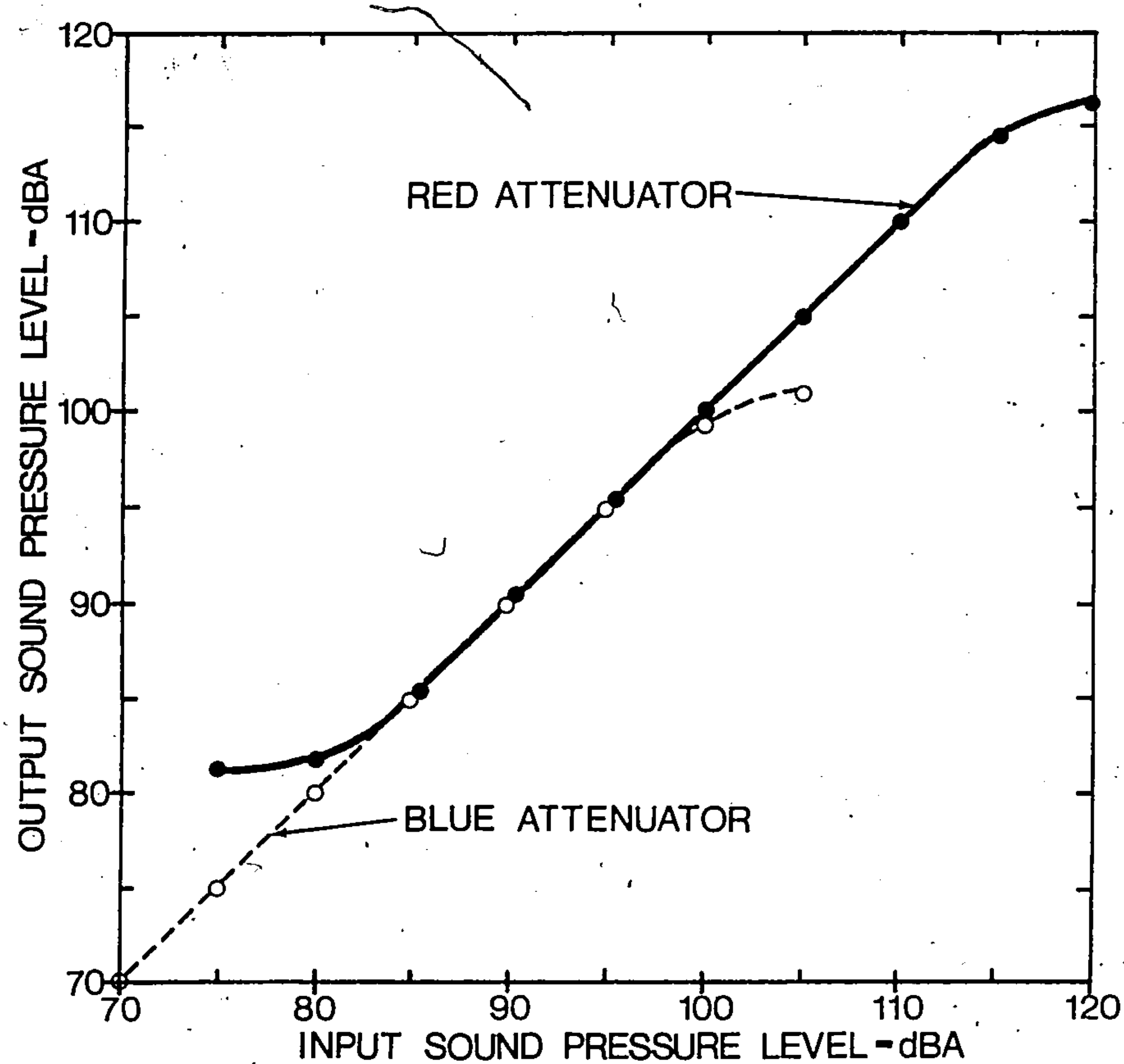

FIGURE 3 TYPICAL DYNAMIC RESPONSE OF EAR BUG

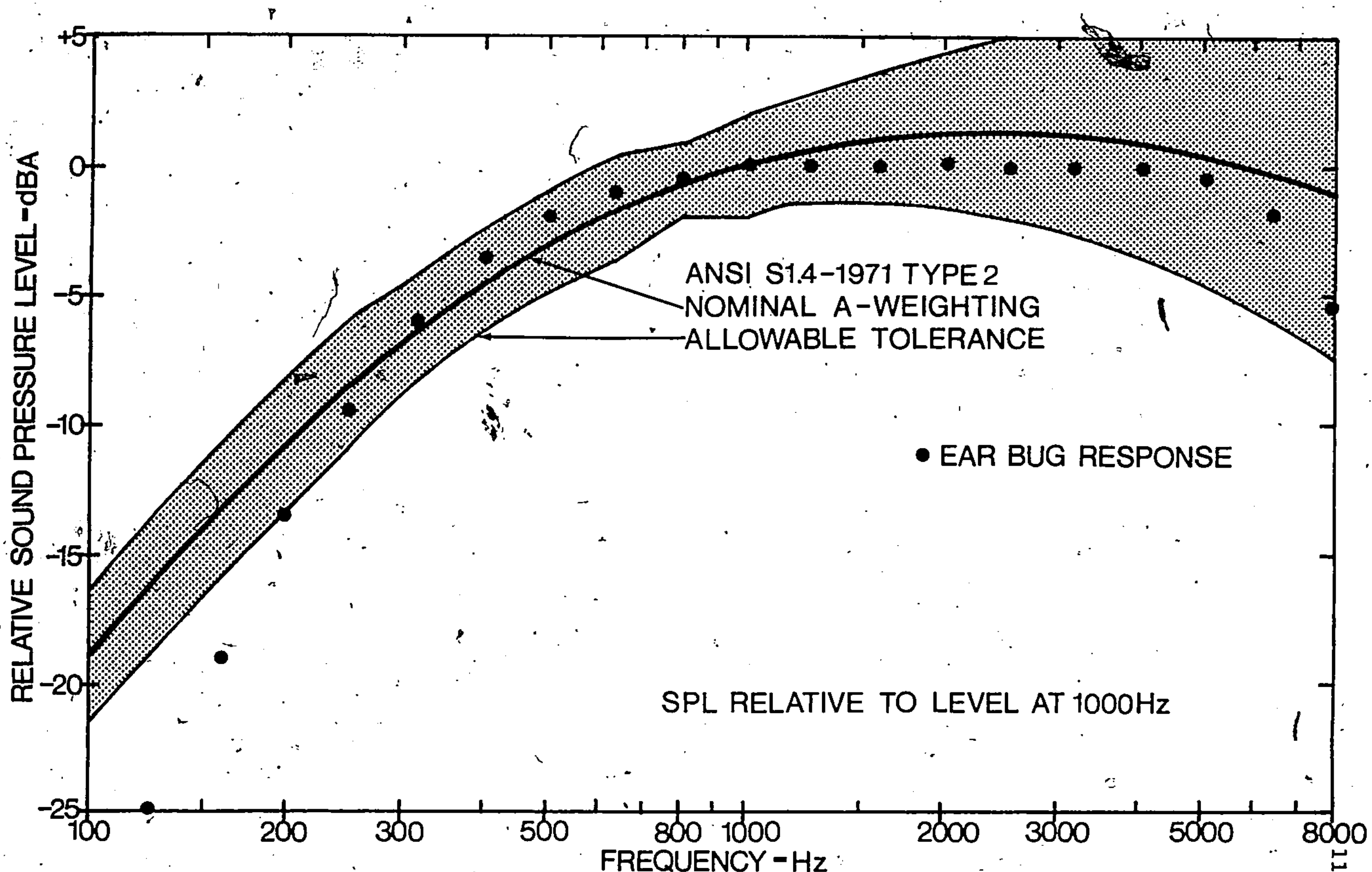

FIGURE 4 TYPICAL FREQUENCY RESPONSE OF EAR BUG

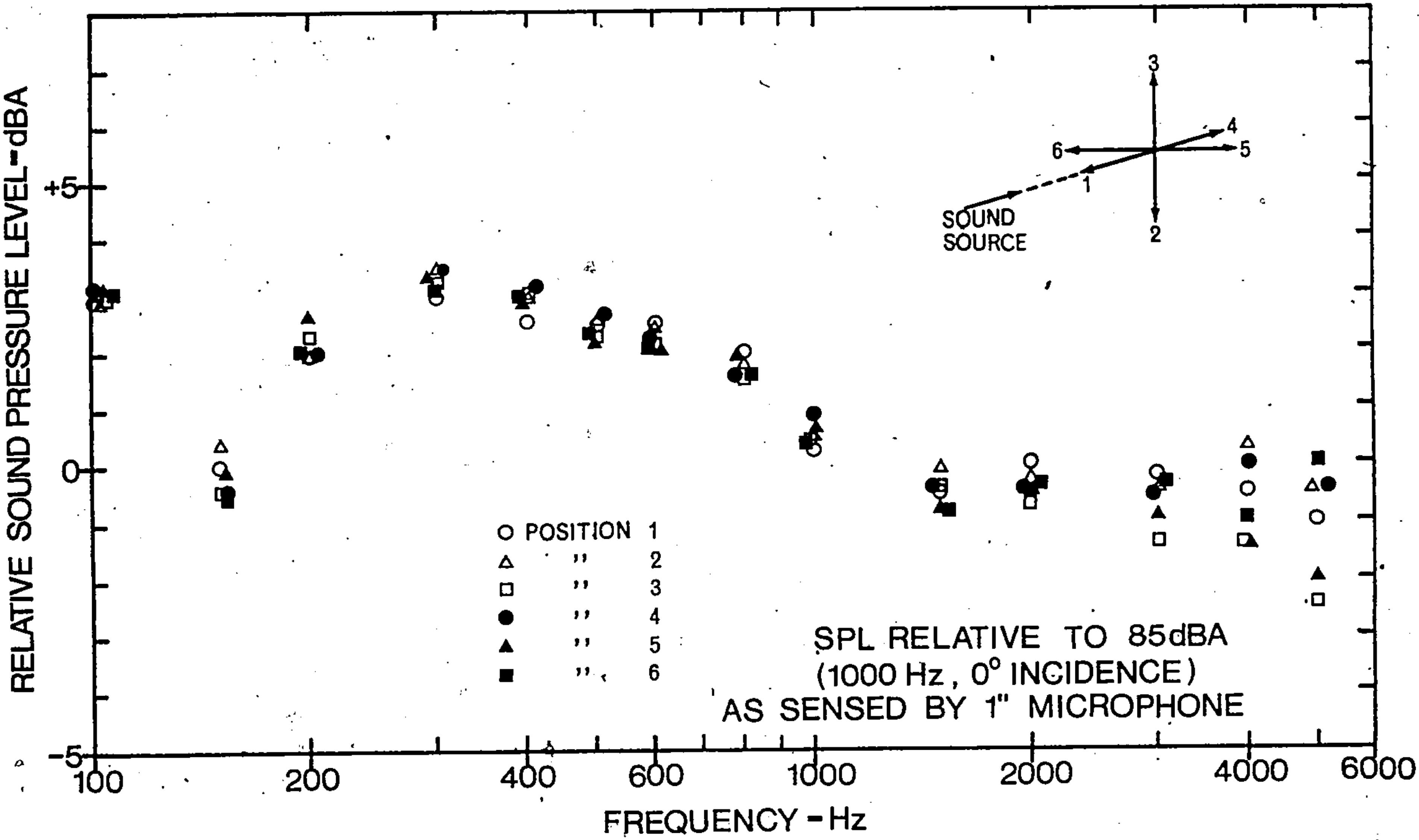

FIGURE 5 TYPICAL DIRECTIONALITY OF EAR BUG

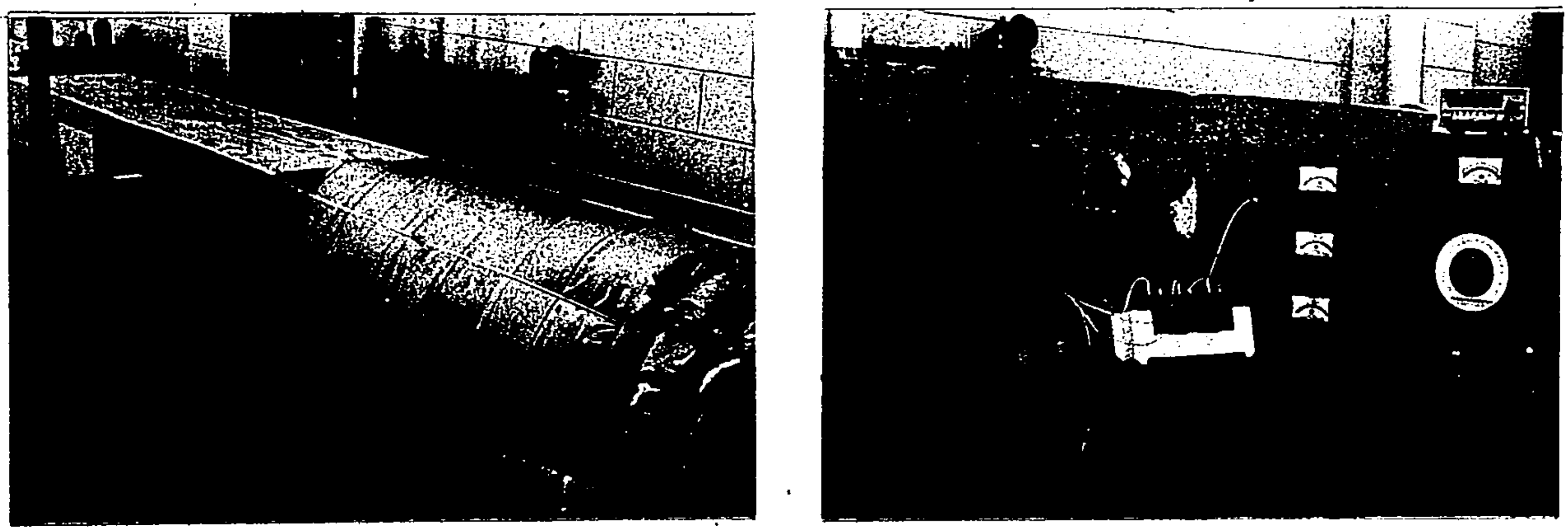

FIGURE 6 PLANE WAVE TUBE

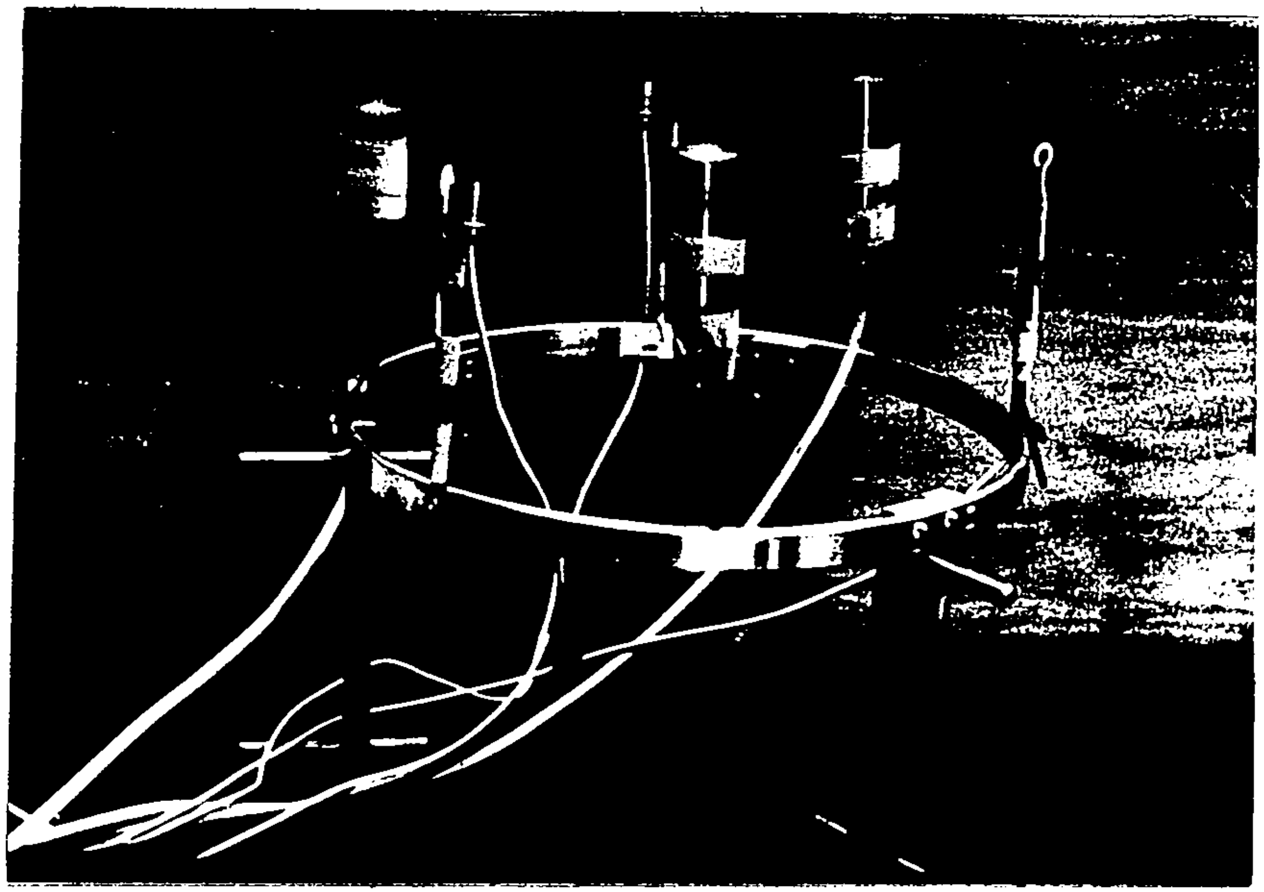

FIGURE 7 MICROPHONE MOUNTING RING

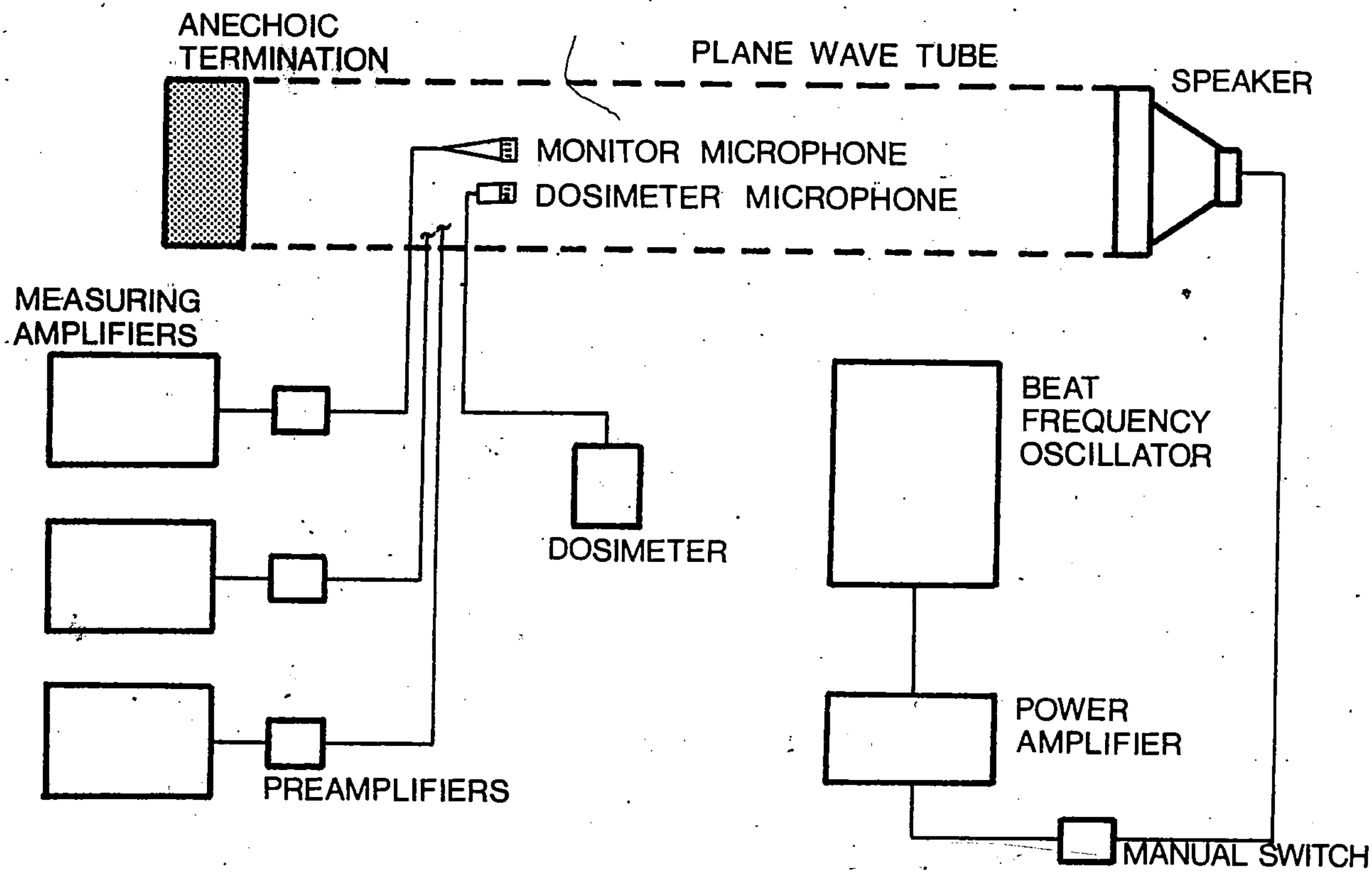

FIGURE 8 DOSIMETER TEST SET-UP

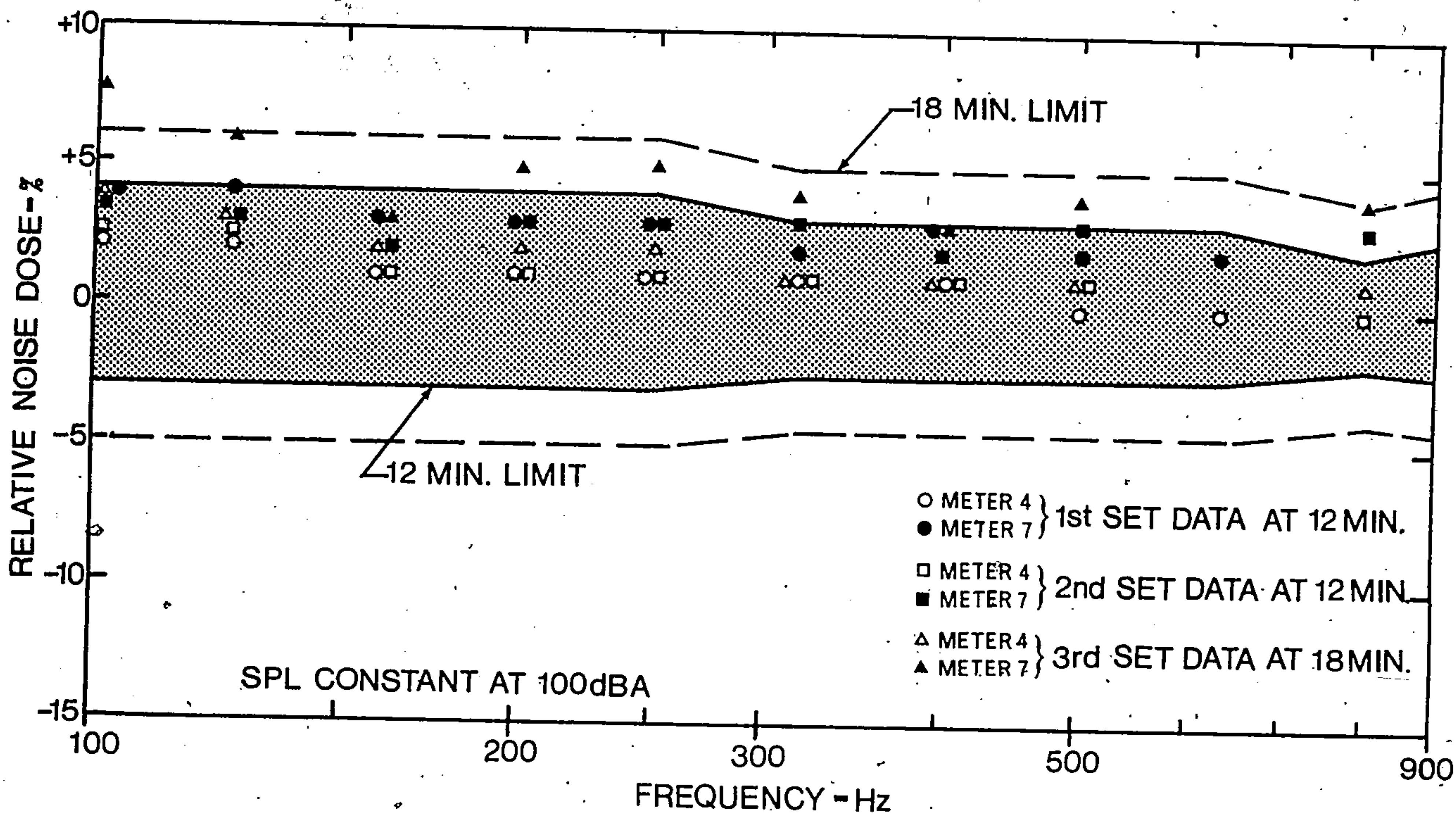

FIGURE 9 EFFECT OF FREQUENCY ON NOISE DOSIMETER RESPONSE

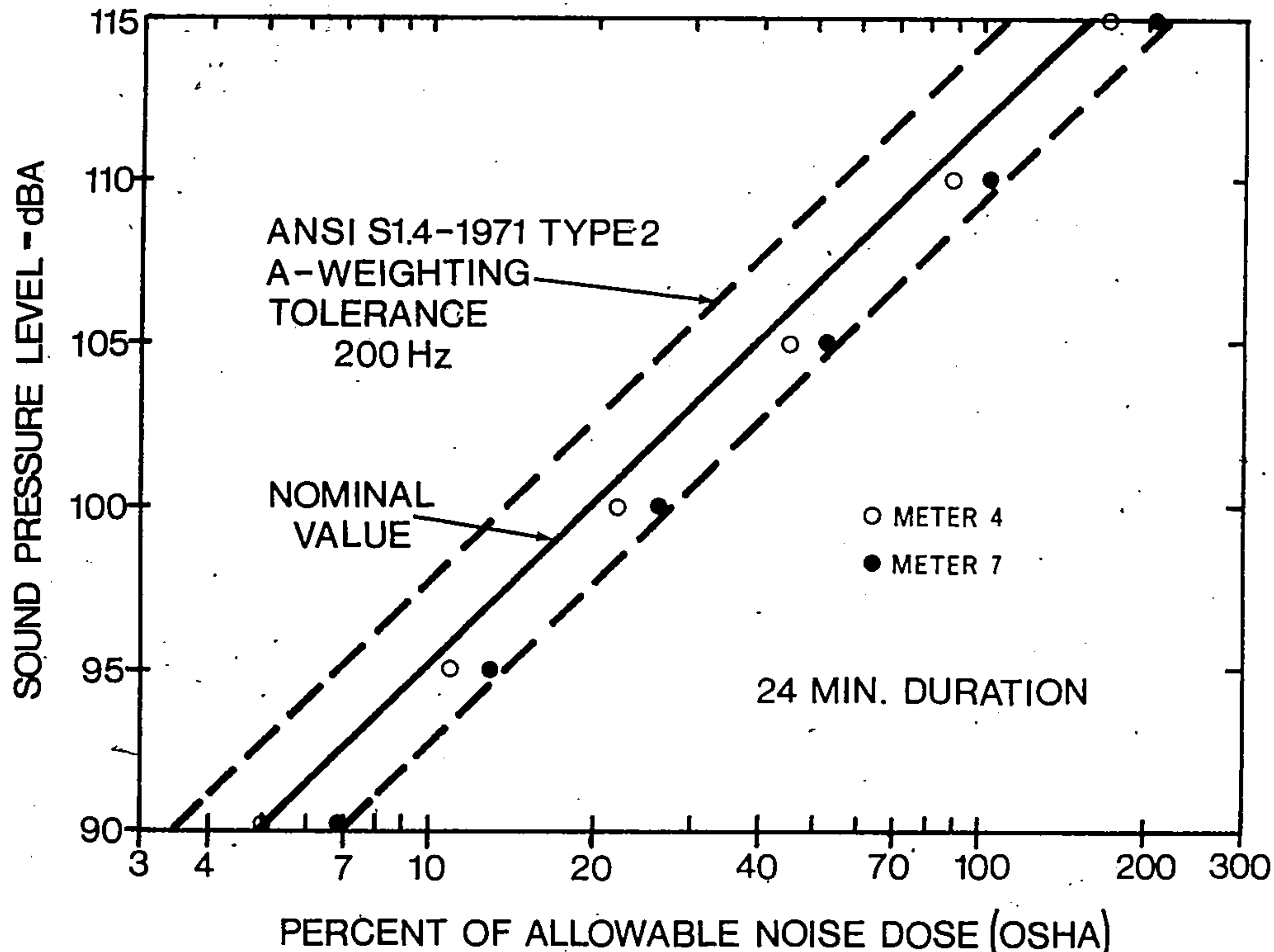

FIGURE 10 EFFECT OF FREQUENCY ON NOISE DOSIMETER RESPONSE

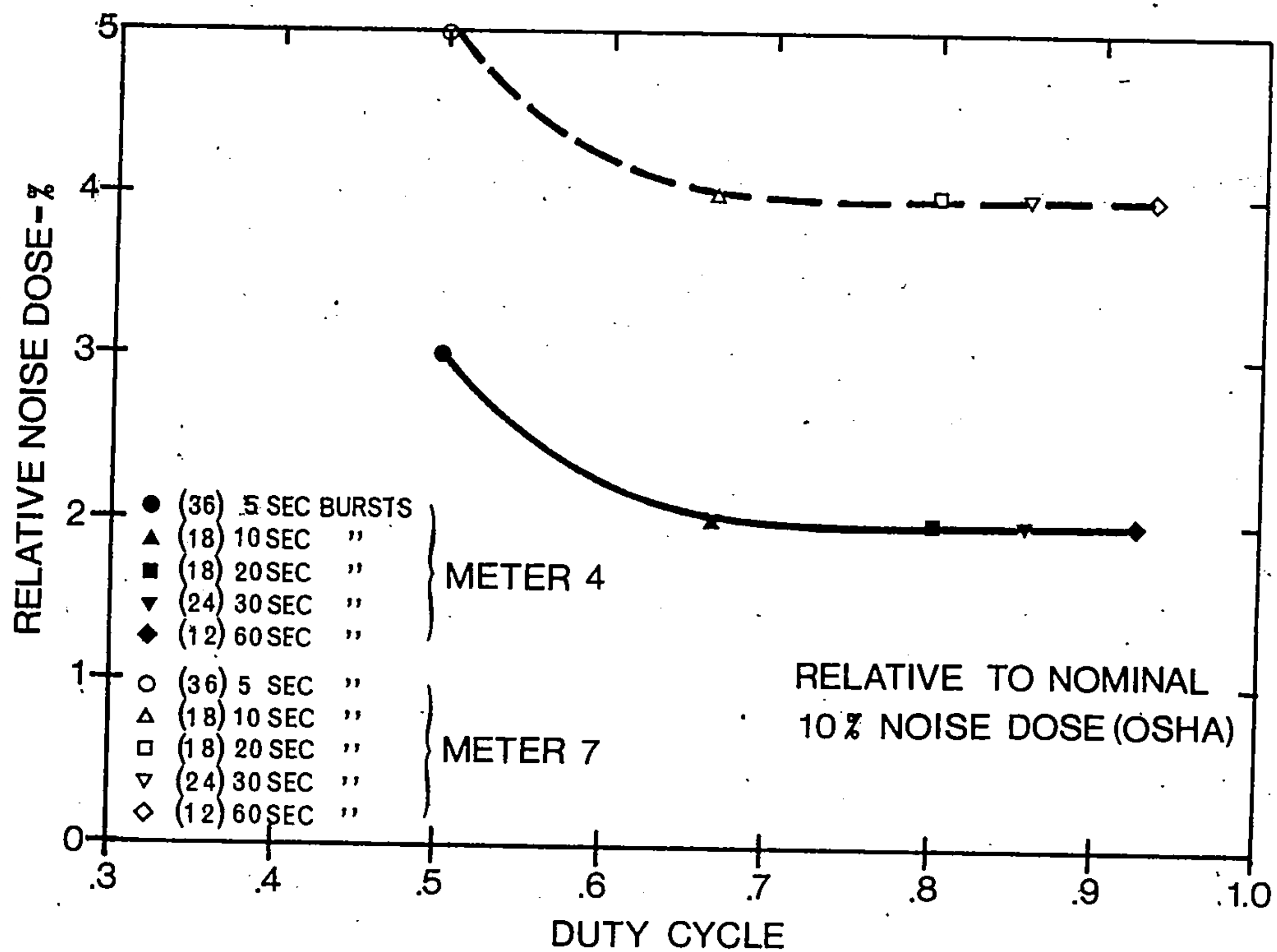

FIGURE 11 DUTY CYCLE VERSUS RELATIVE NOISE DOSE

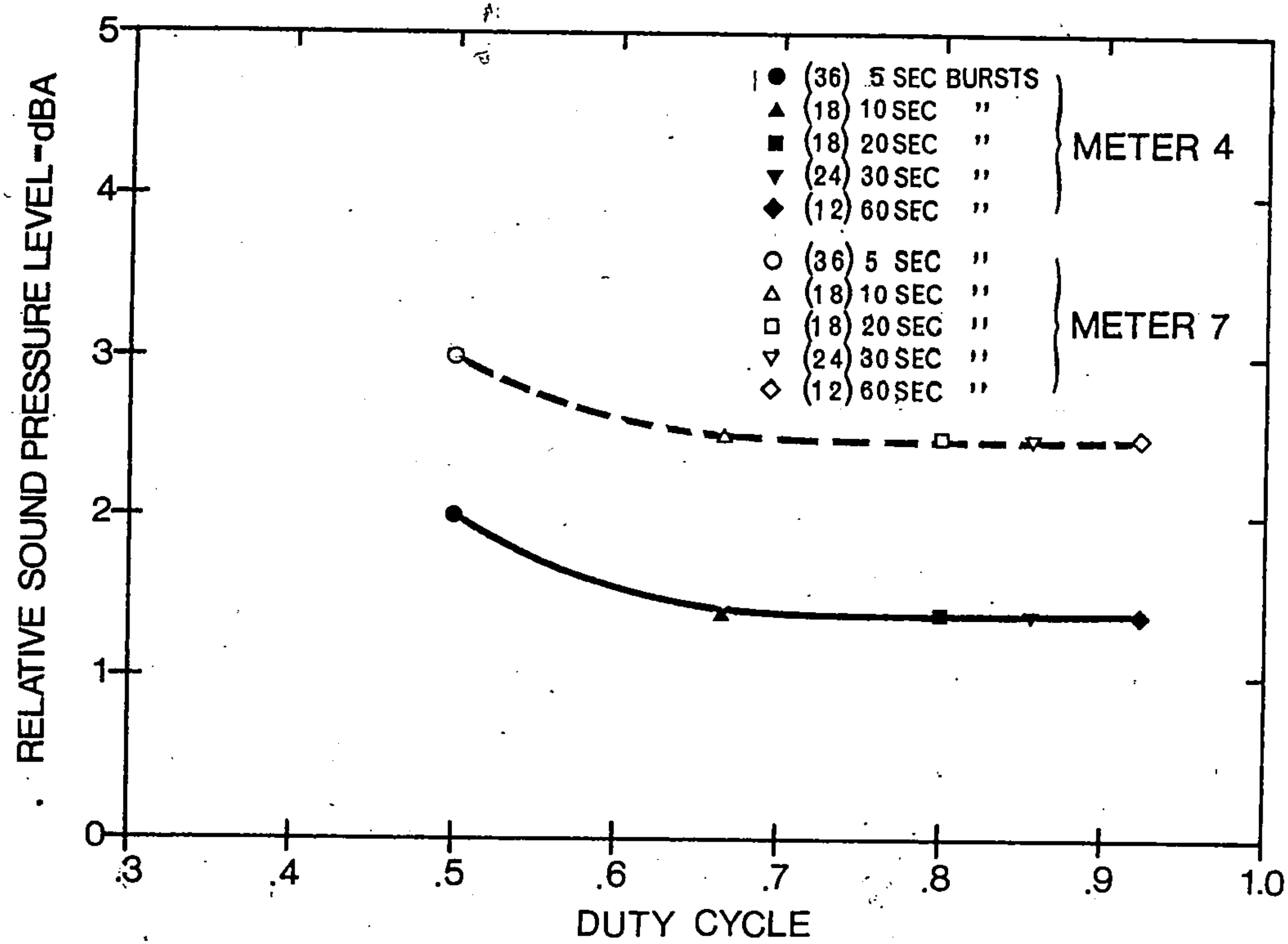

FIGURE 12 DUTY CYCLE VERSUS RELATIVE LEVEL

FIGURE 13 MANNEQUIN IN TEST POSITION

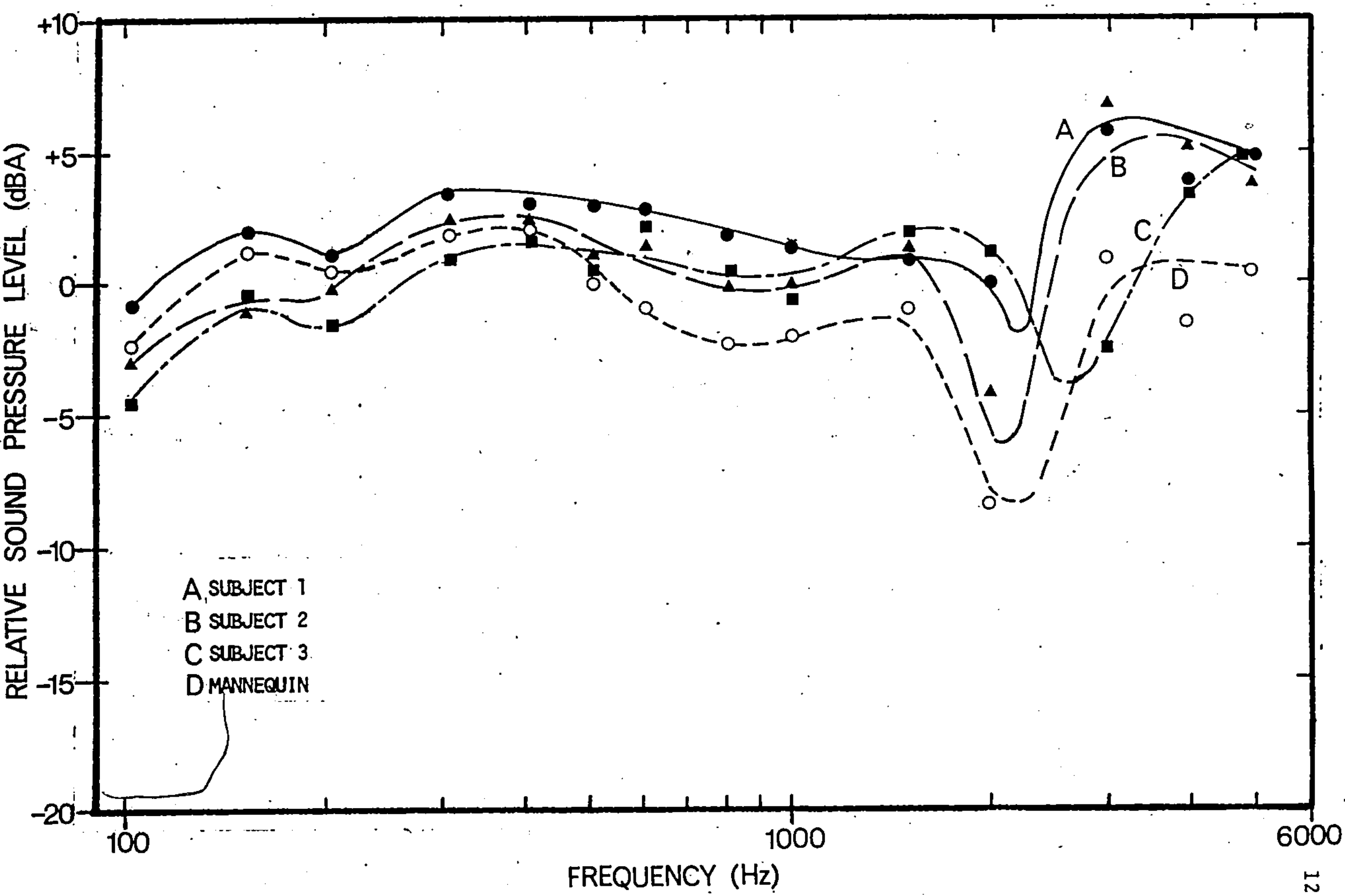

FIGURE 14 "AT EAR" RELATIVE RESPONSE FOR DIFFERENT SUBJECTS

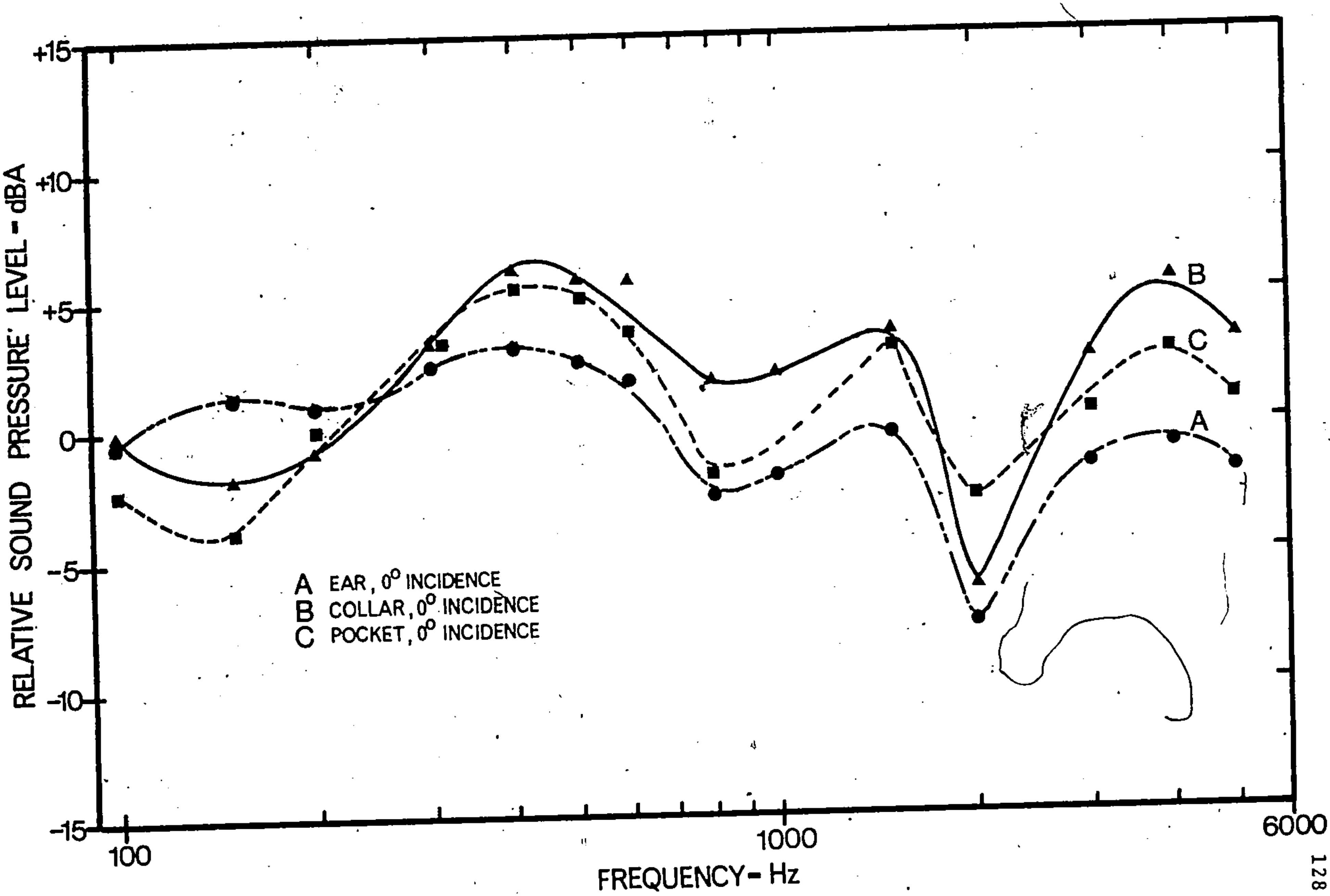

FIGURE 15 RELATIVE RESPONSE FOR VARIOUS MICROPHONE MOUNTING POSITIONS

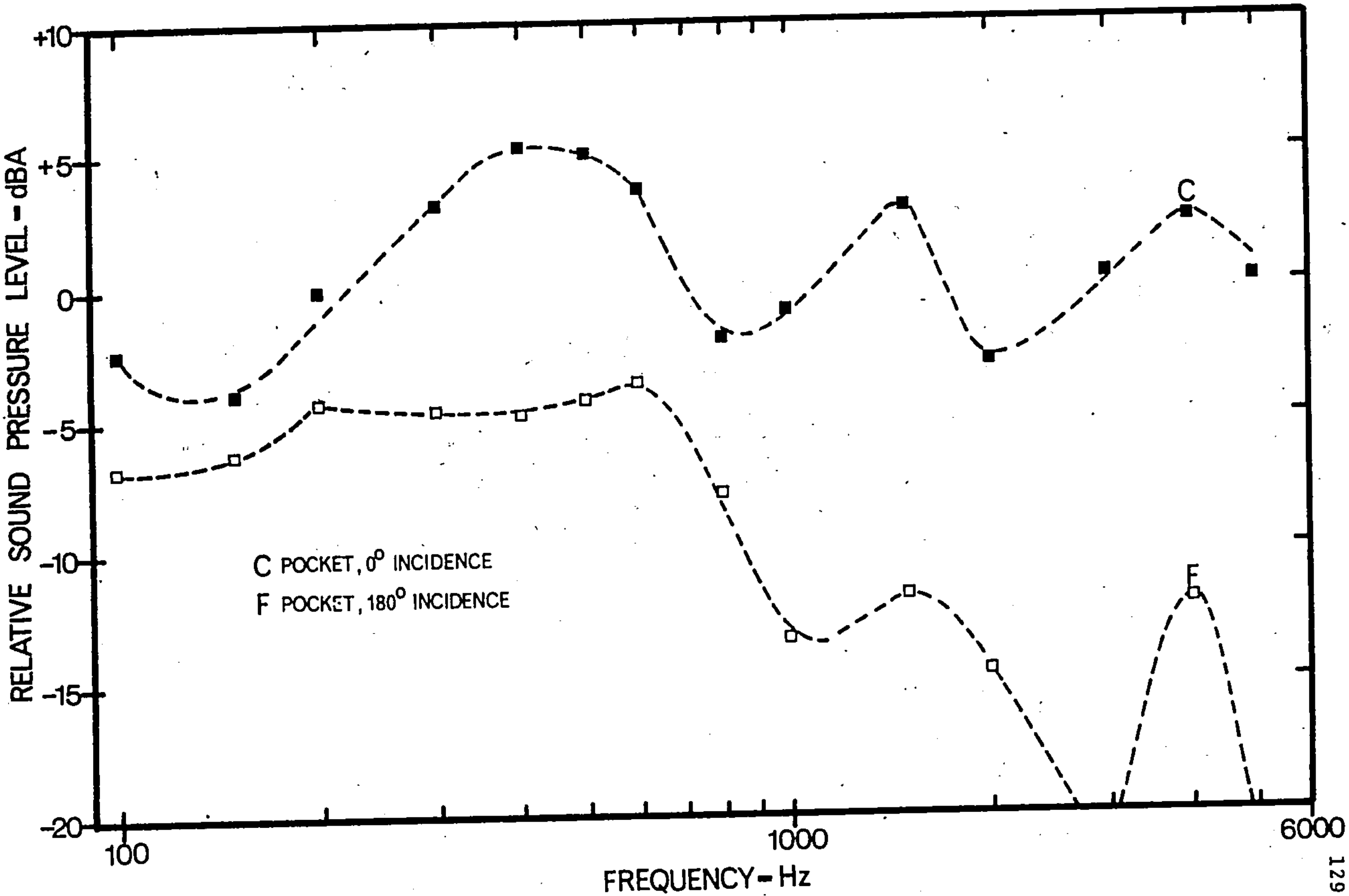

FIGURE 16 EFFECT OF INCIDENCE ON RELATIVE RESPONSE FOR THE "AT BREAST POCKET" POSITION

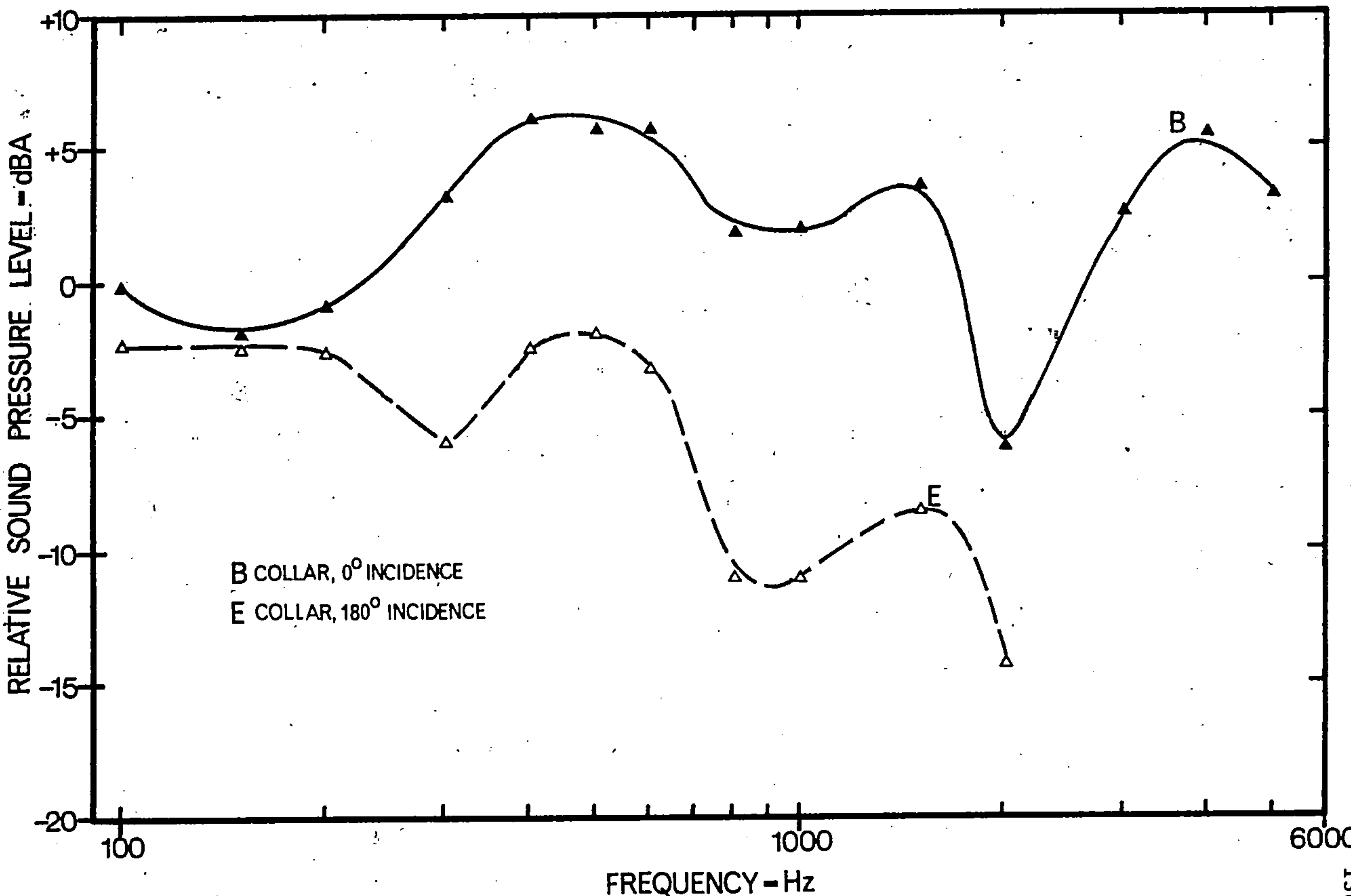

FIGURE 17 EFFECT OF INCIDENCE ON RELATIVE RESPONSE FOR THE "AT COLLAR" POSITION

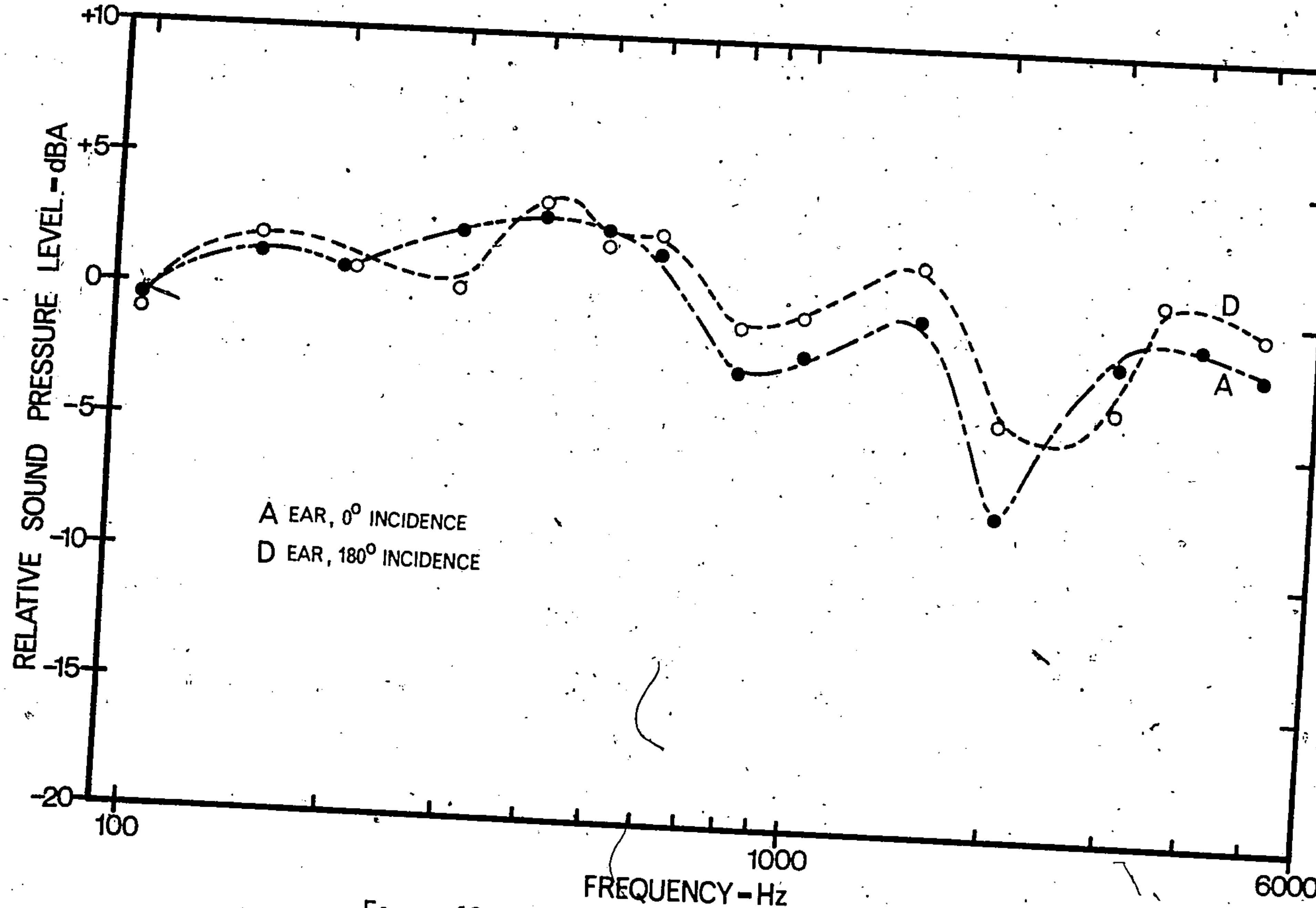

FIGURE 18 EFFECT OF INCIDENCE ON RELATIVE RESPONSE FOR THE "AT EAR" POSITION

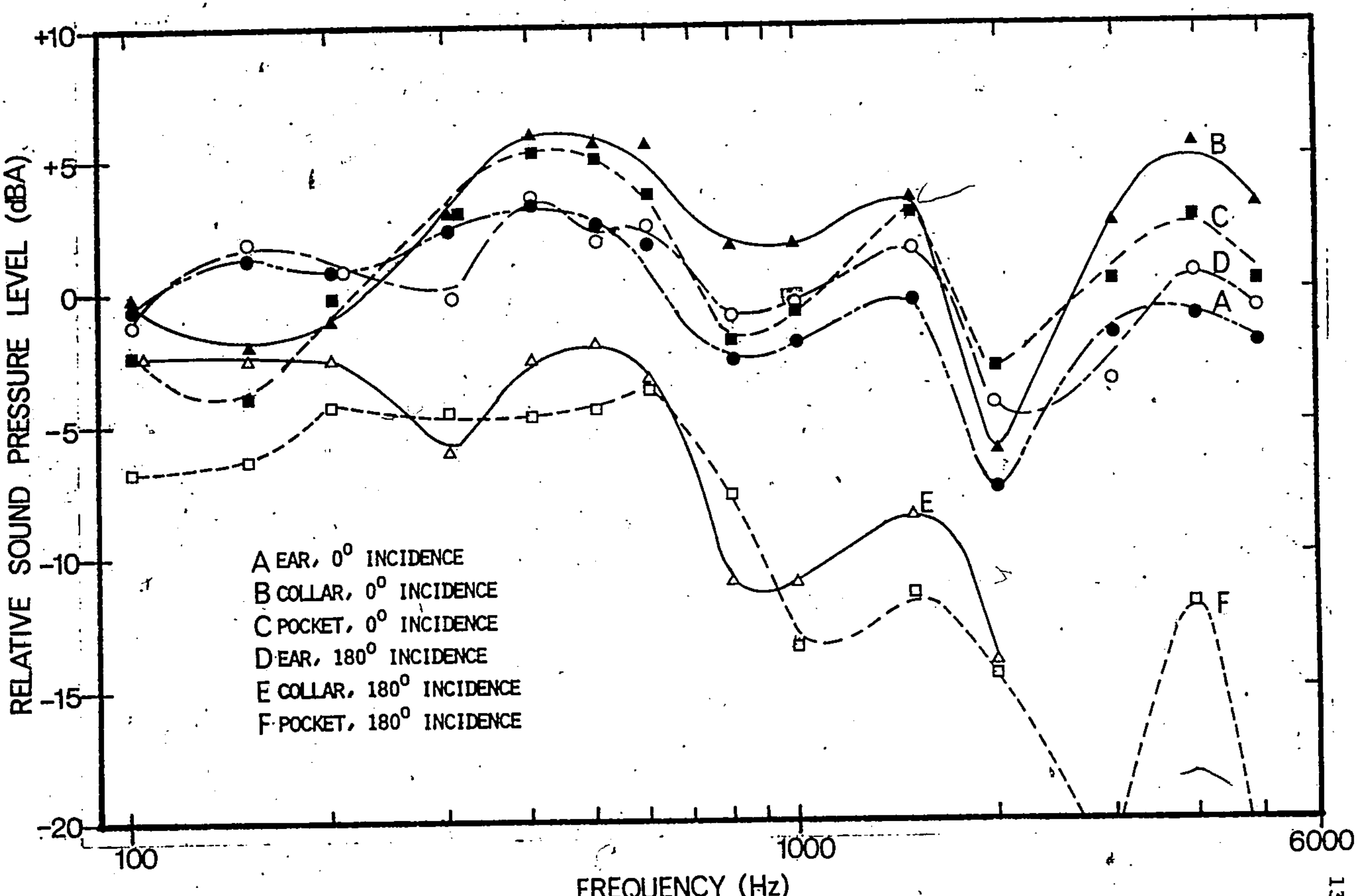

FIGURE 19 - RELATIVE RESPONSE FOR VARIOUS MICROPHONE POSITIONS AND SOUND INCIDENCE

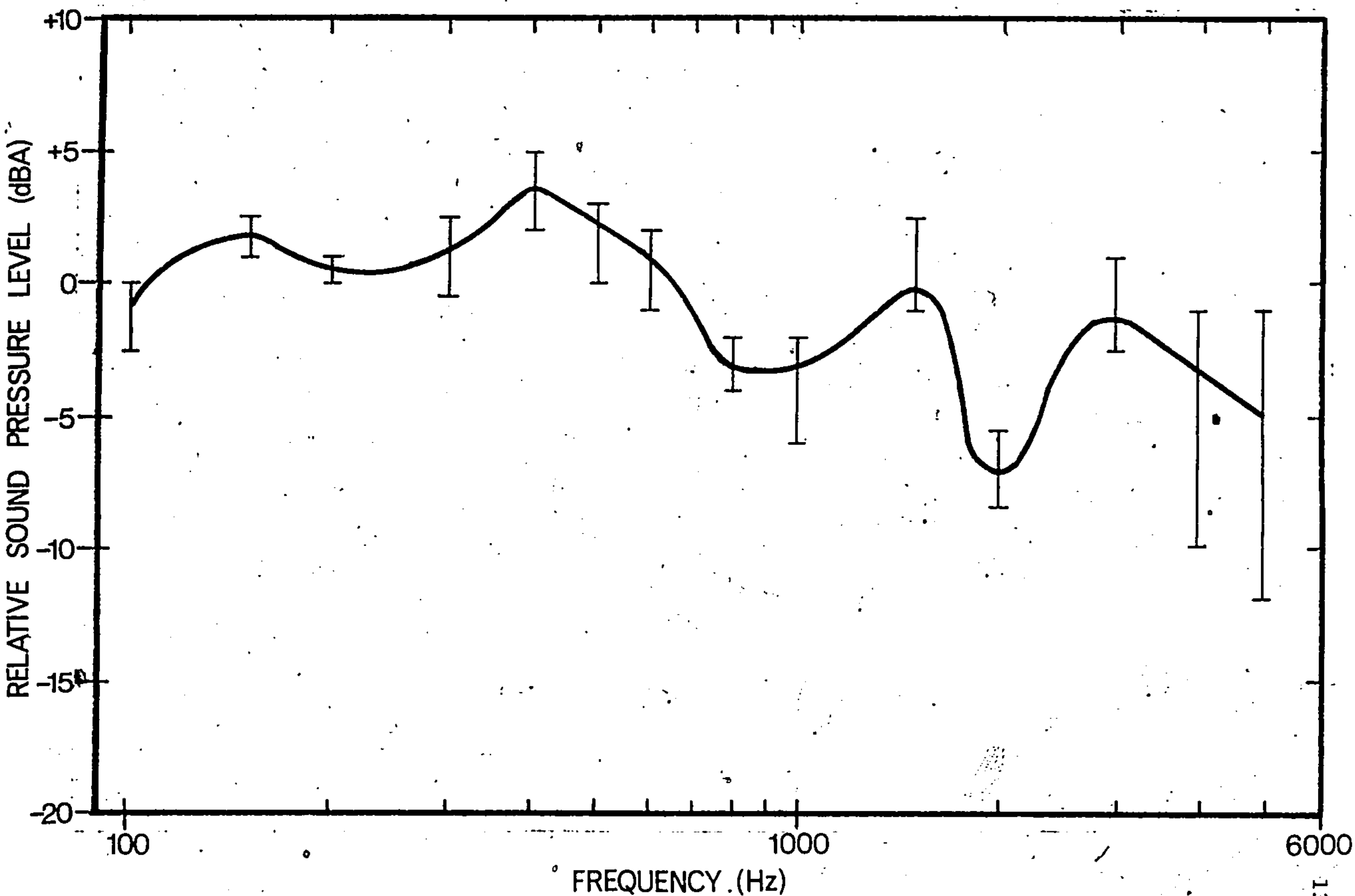

FIGURE 20 EFFECT OF CLOTHING VARIATIONS ON RELATIVE RESPONSE

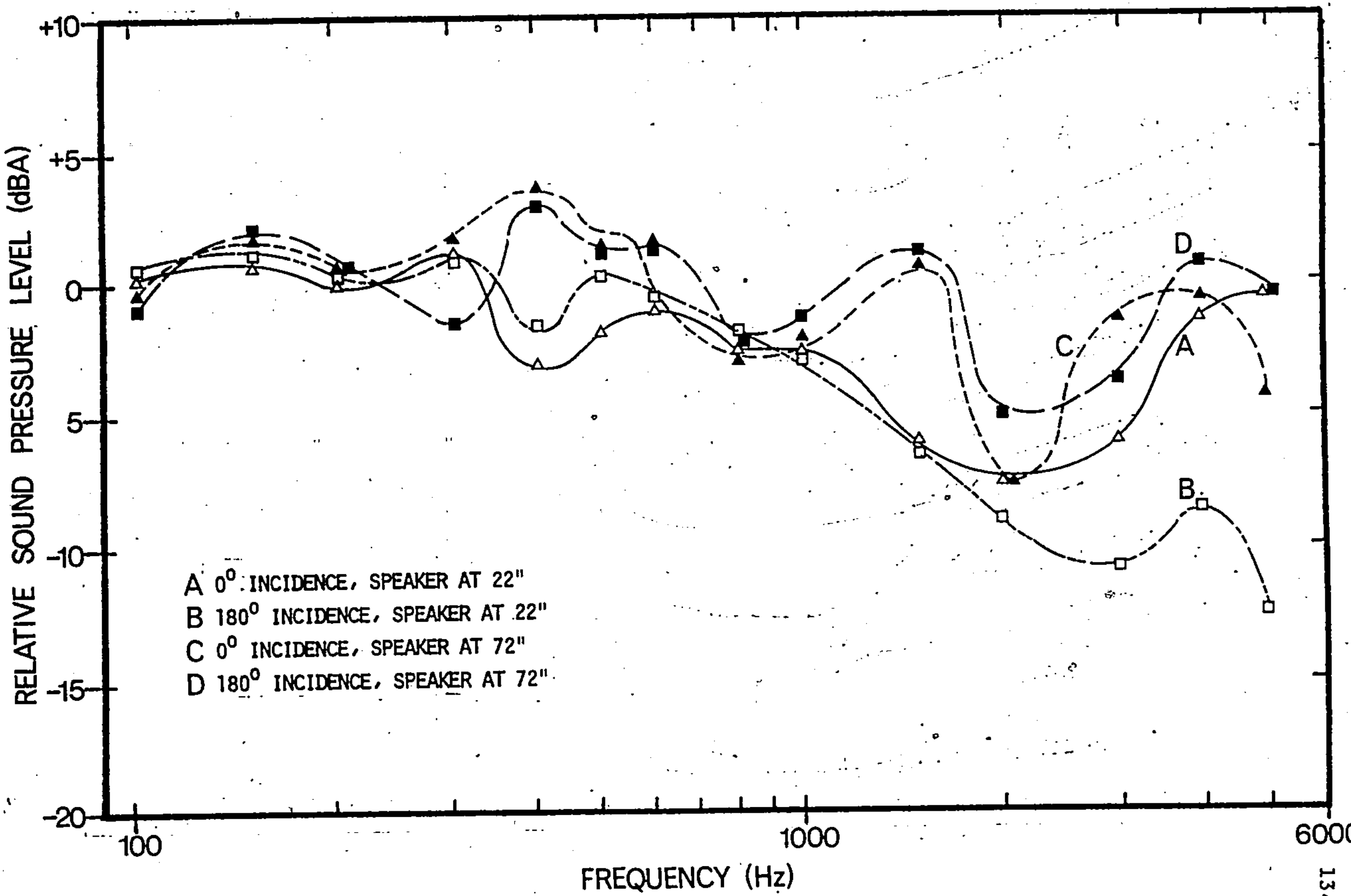

FIGURE 21 EFFECT OF SOUND SOURCE POSITION ON RELATIVE RESPONSE

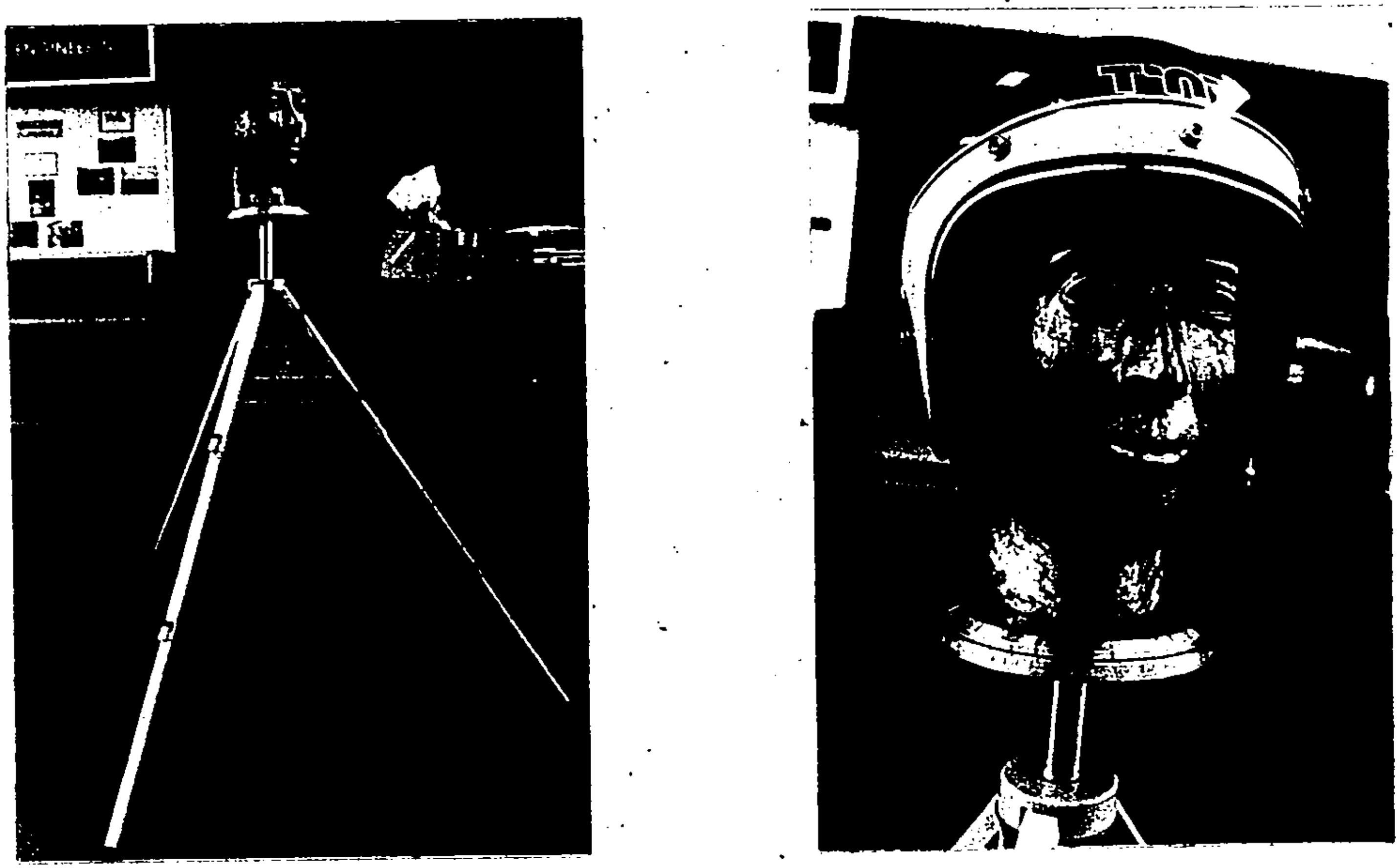

FIGURE 22 NIBS MOUNTED ON TRIPOD

FIGURE 23 NIBS - EAR BUG MOUNTING

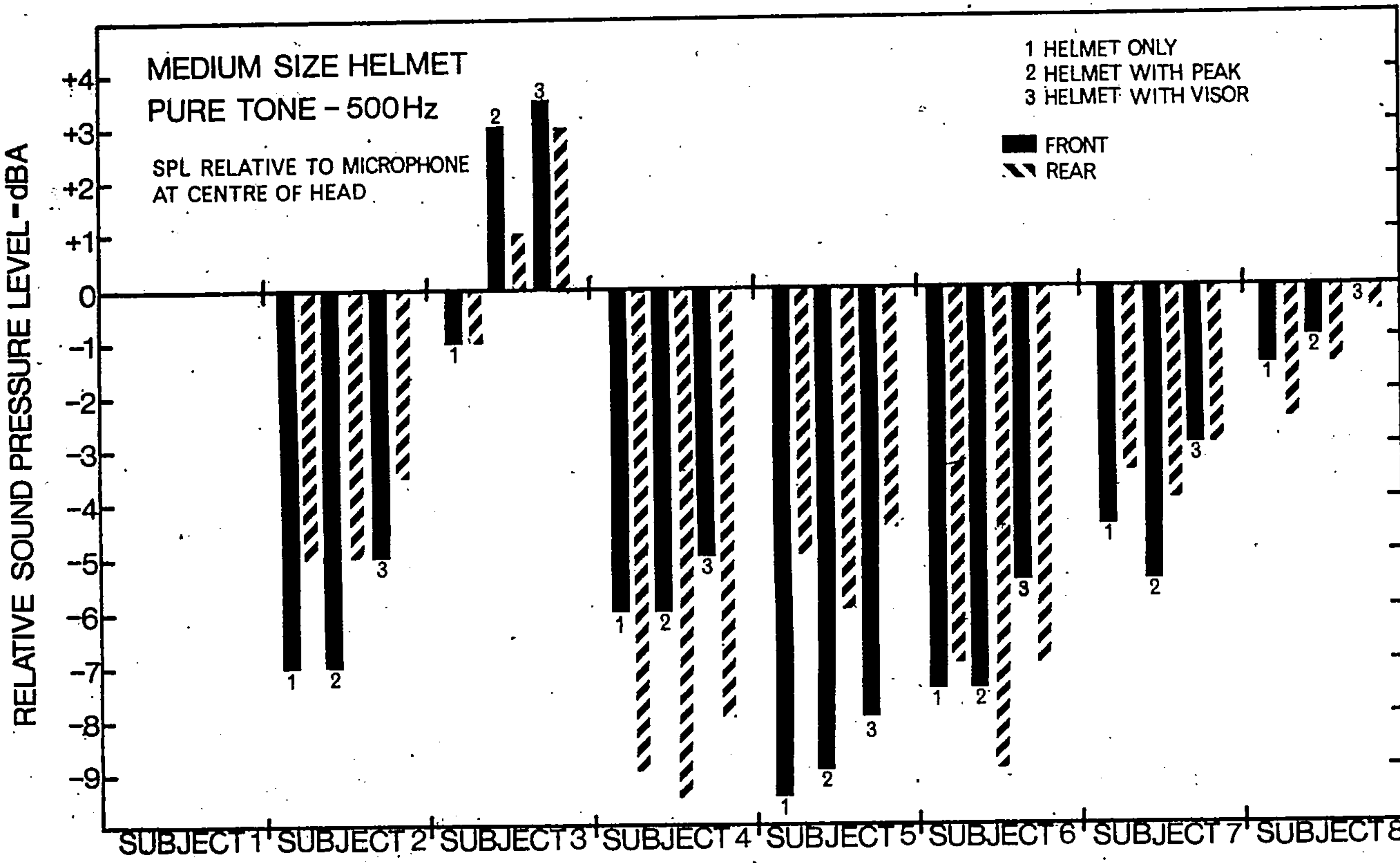

FIGURE 24 RELATIVE SPL FOR MEDIUM HELMET AND 500 Hz PURE TONE – RELATIVE TO MICROPHONE AT CENTRE OF HEAD

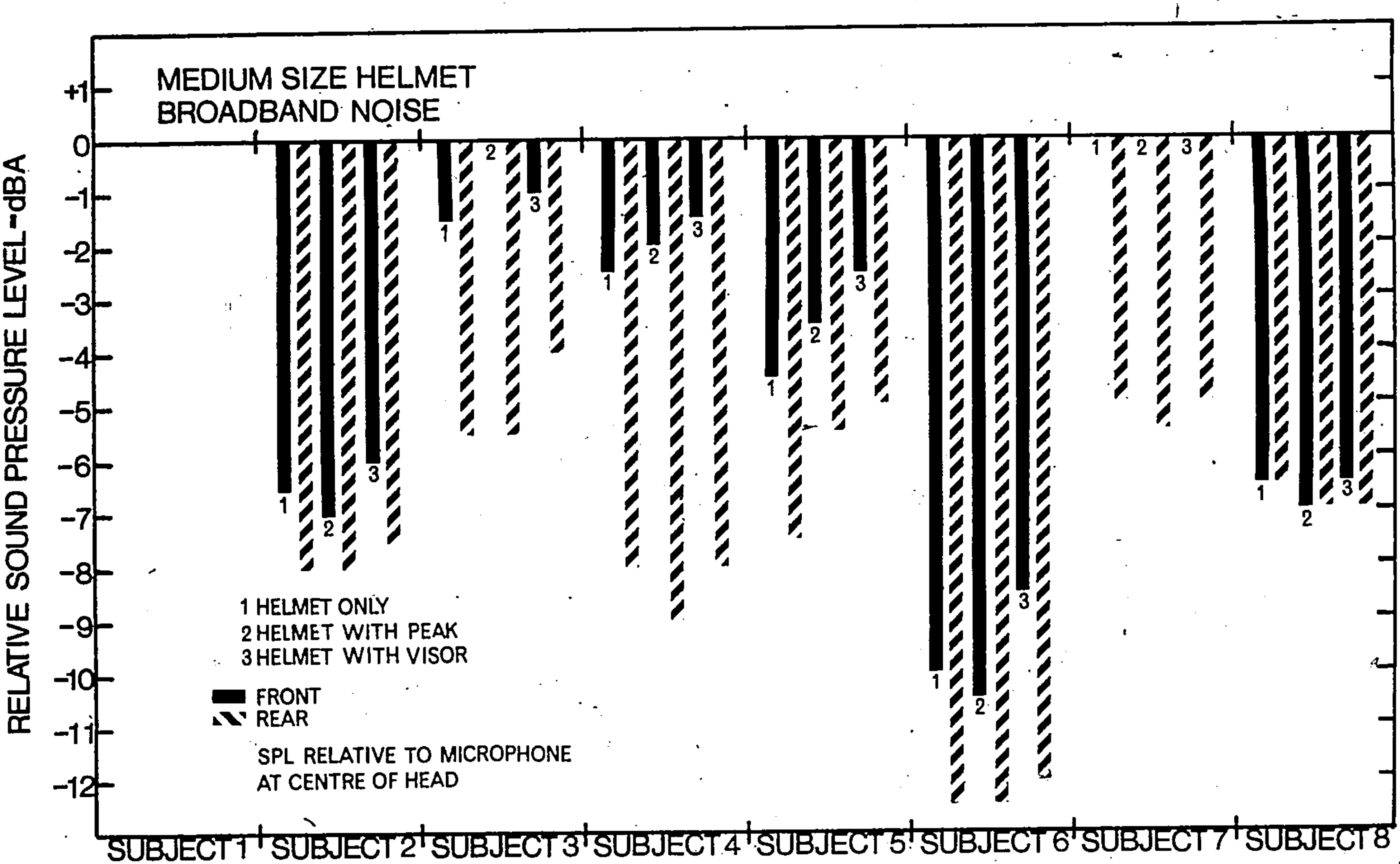

FIGURE 25 RELATIVE SPL FOR MEDIUM HELMET AND BROADBAND NOISE - RELATIVE TO MICROPHONE AT CENTRE OF HEAD

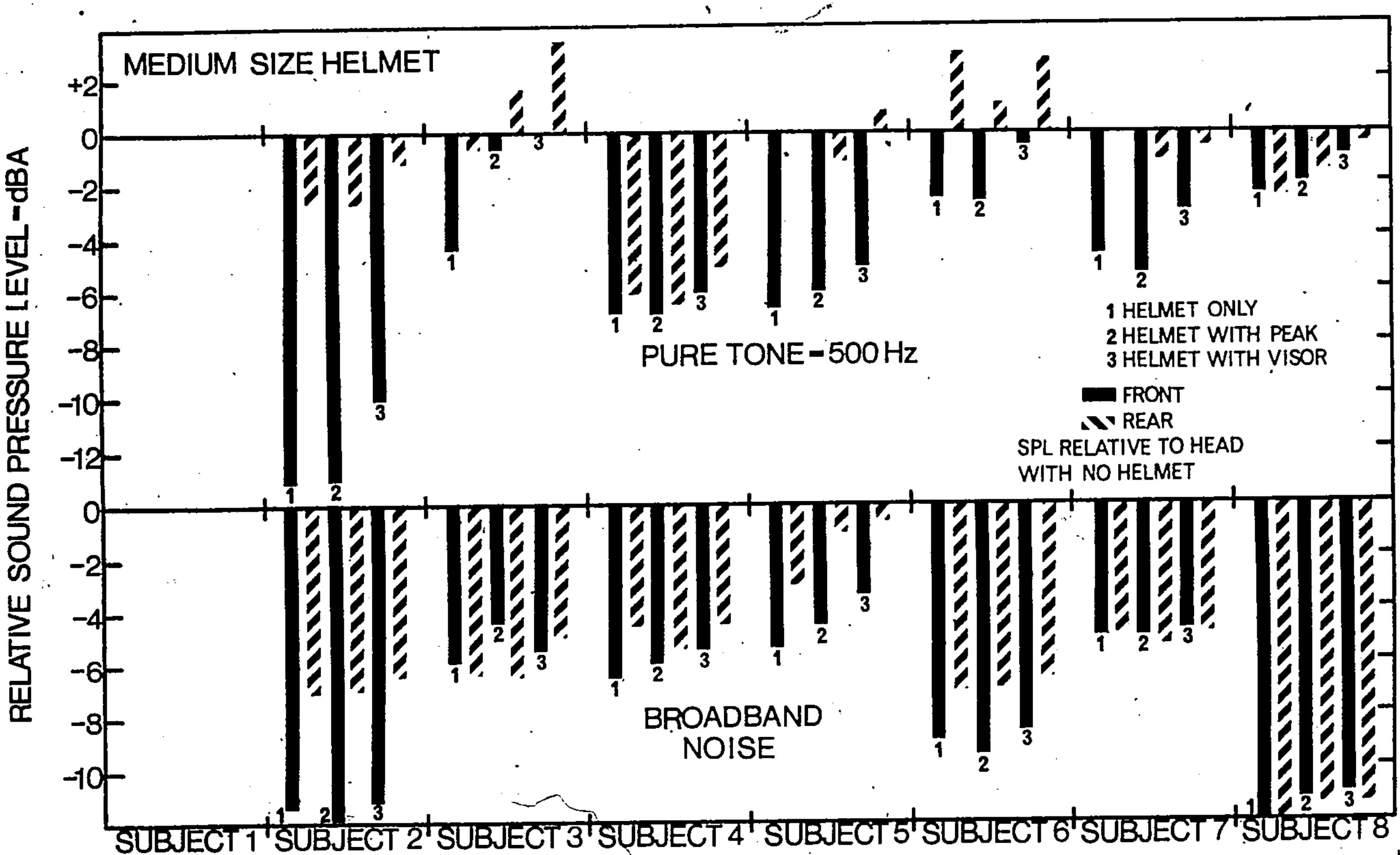

FIGURE 26 RELATIVE SPL FOR MEDIUM HELMET FOR BOTH 500 Hz PURE TONE AND BROADBAND NOISE - RELATIVE TO HEAD WITH NO HELMET

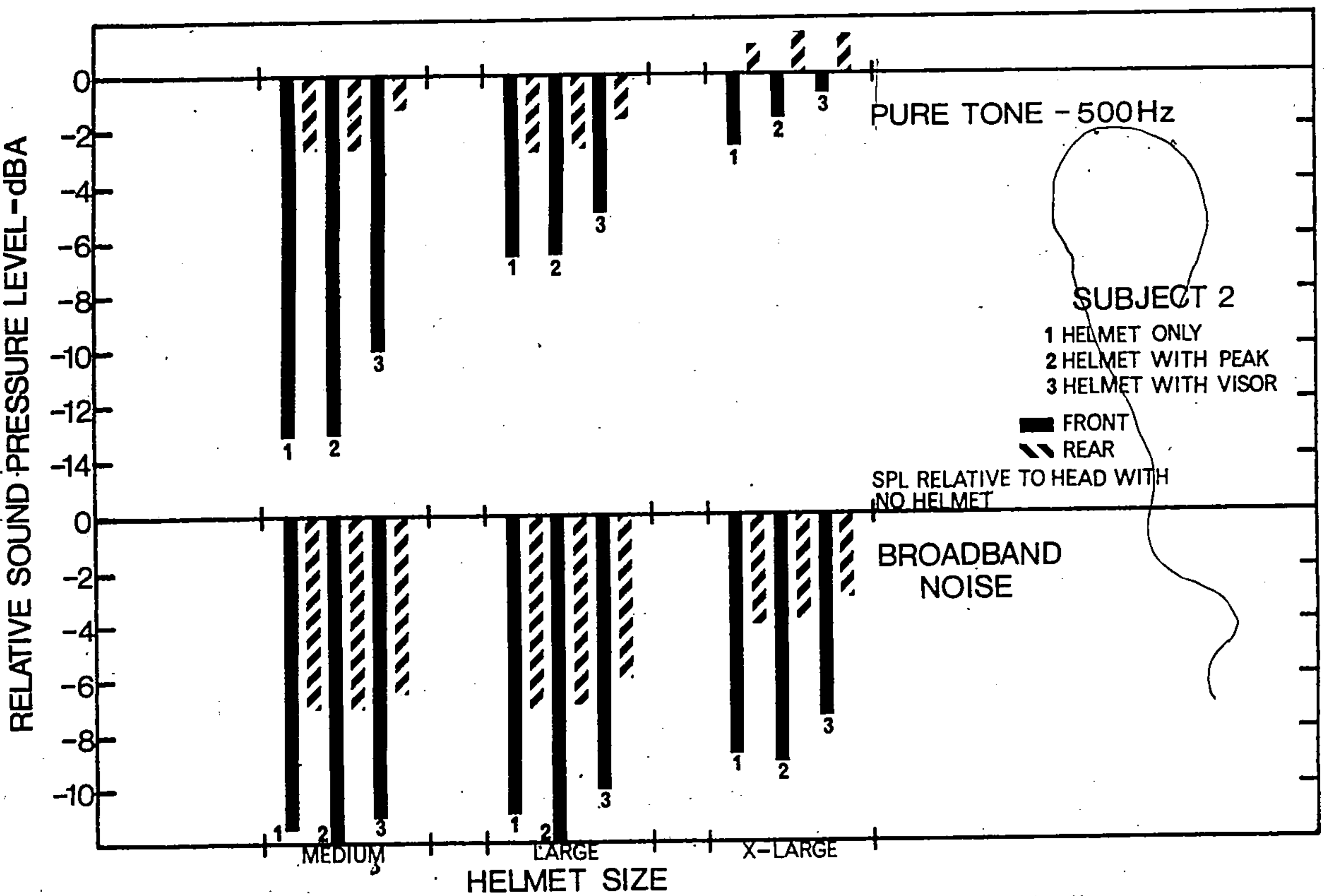

FIGURE 27 RELATIVE SPL FOR SUBJECT 2 FOR BOTH 500 Hz PURE TONE AND BROADBAND NOISE - RELATIVE TO HEAD WITH NO HELMET

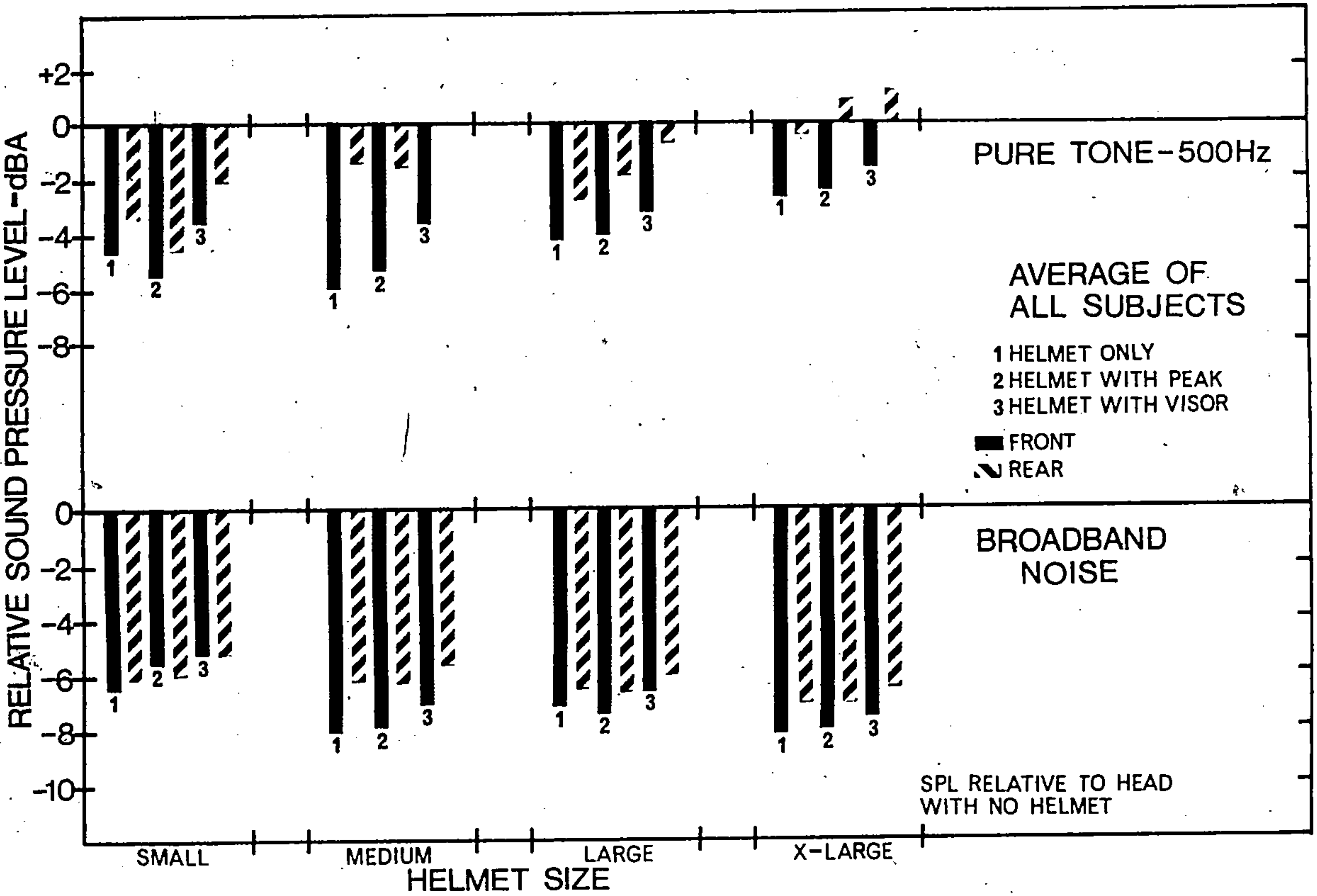

FIGURE 28 RELATIVE SPL FOR AVERAGE OF ALL SUBJECTS FOR BOTH 500 Hz PURE TONE AND BROADBAND NOISE - RELATIVE TO HEAD WITH NO HELMET

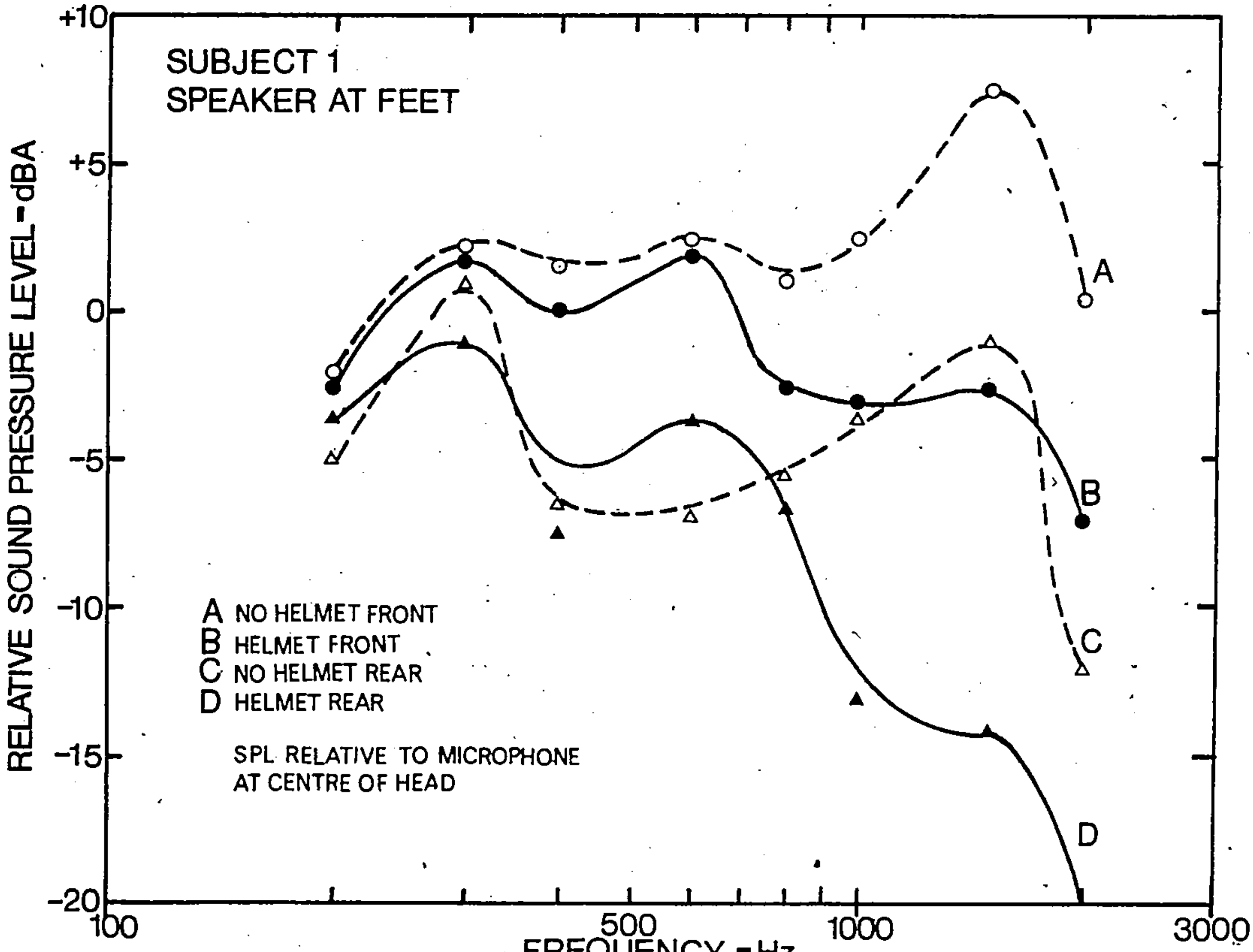

FIGURE 29 EFFECT OF FREQUENCY ON RELATIVE SPL FOR SUBJECT 1 WEARING MEDIUM HELMET - RELATIVE TO MICROPHONE AT CENTRE OF HEAD

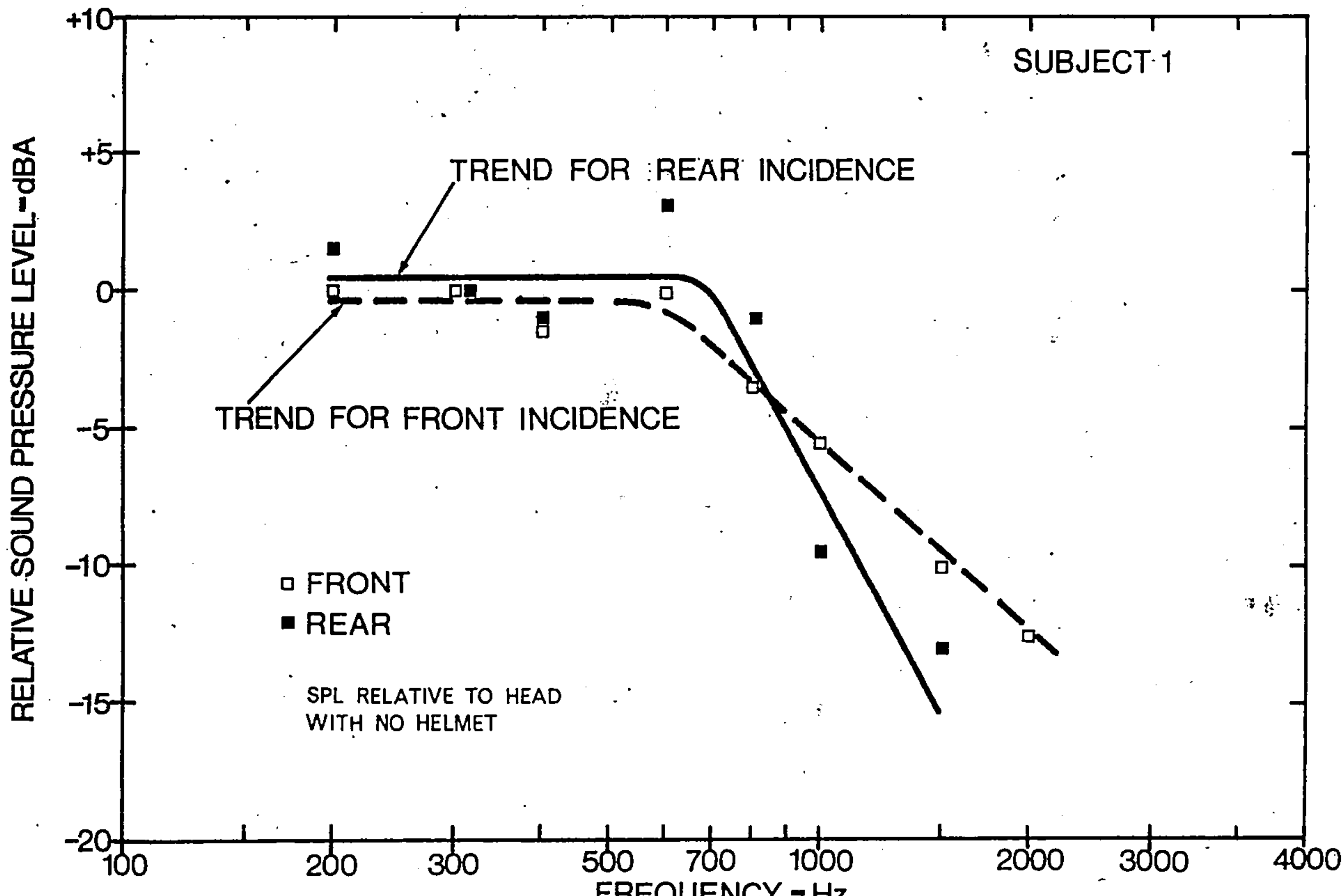

FIGURE 30 FREQUENCY VERSUS RELATIVE SPL FOR SUBJECT 1 AND MEDIUM HELMET - RELATIVE TO HEAD WITH NO HELMET

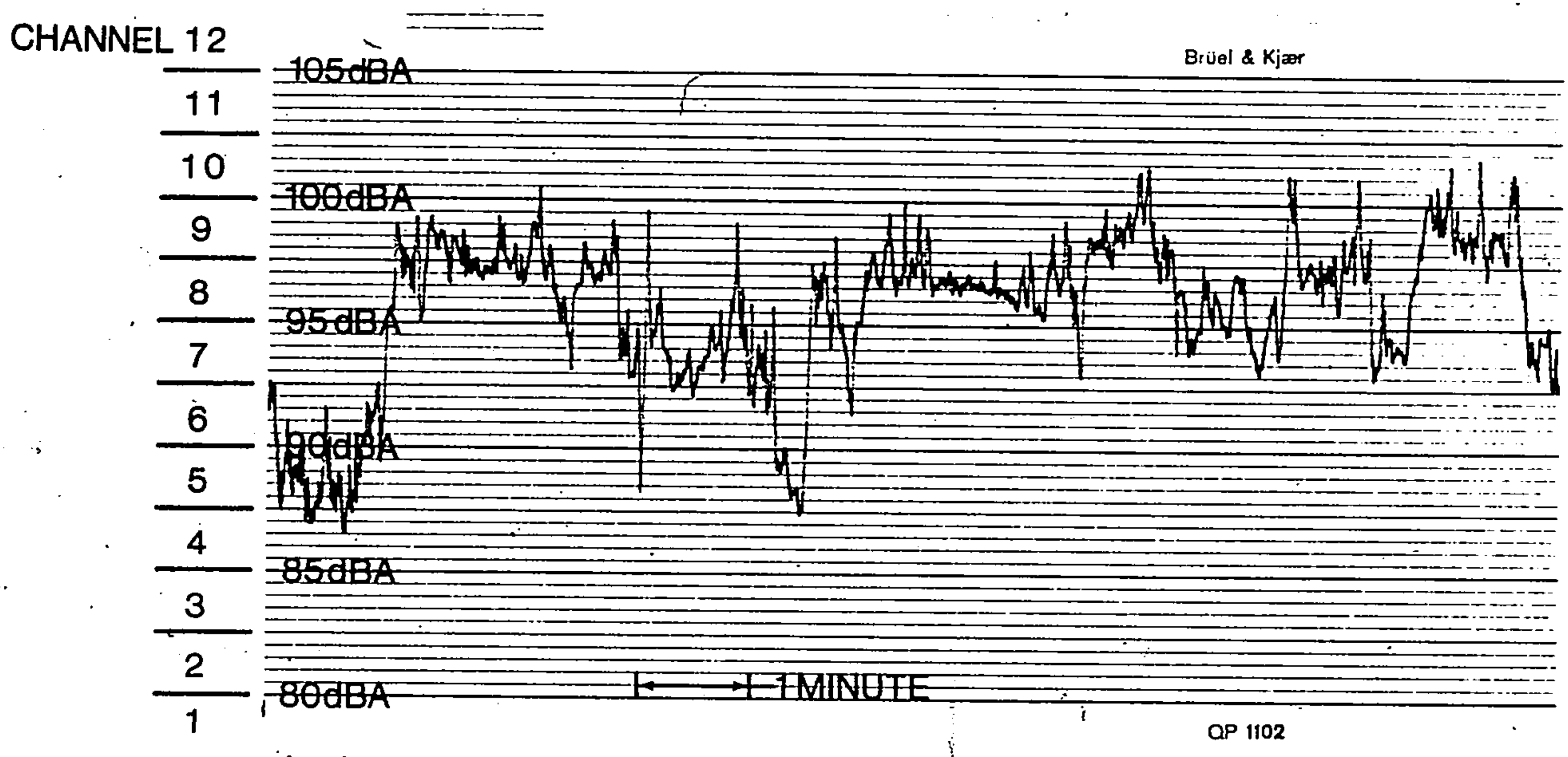

FIGURE 31 TWELVE CHANNEL RESOLUTION OF LEVEL RECORDER OUTPUT

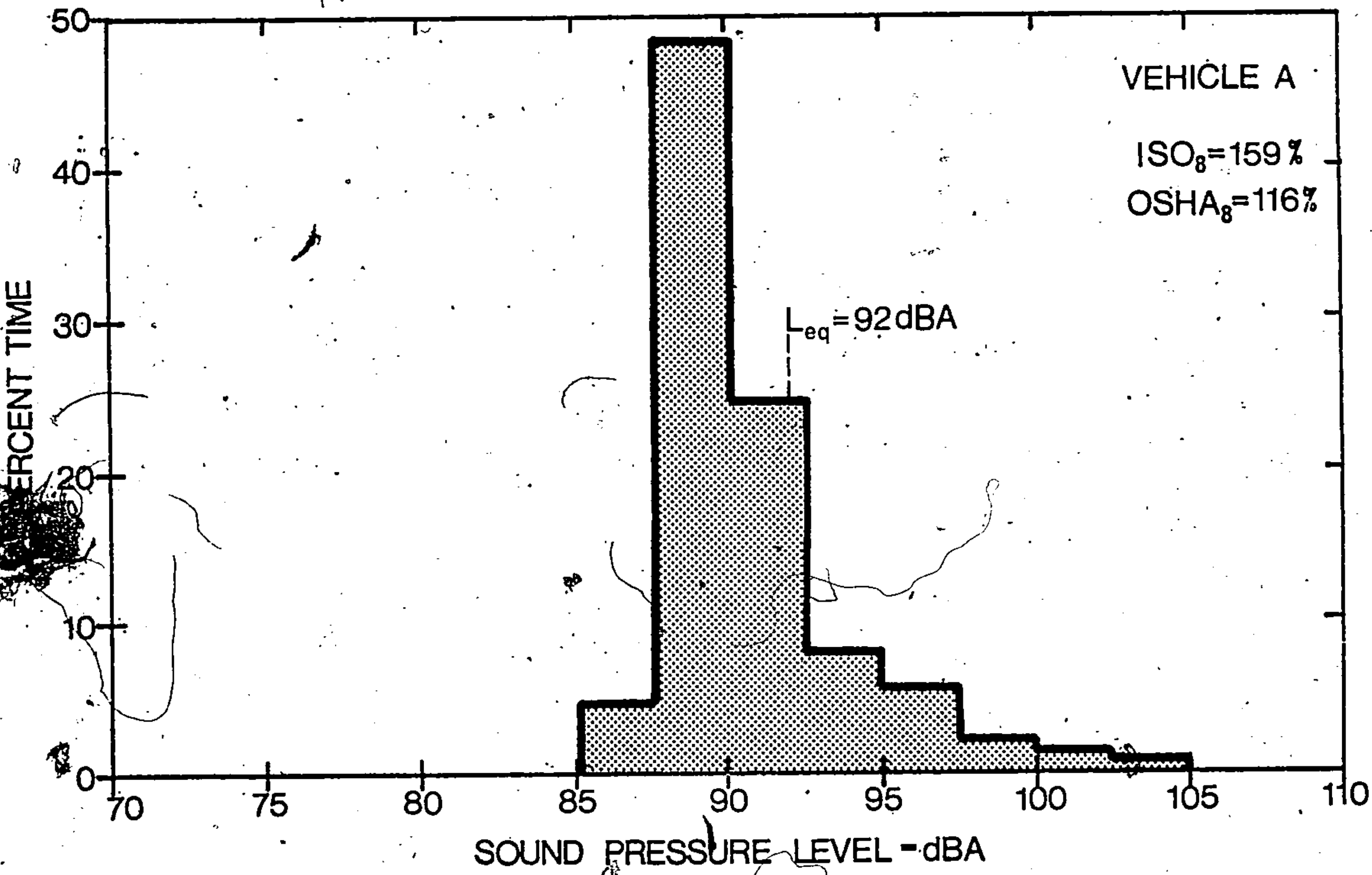

FIGURE 32 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE A

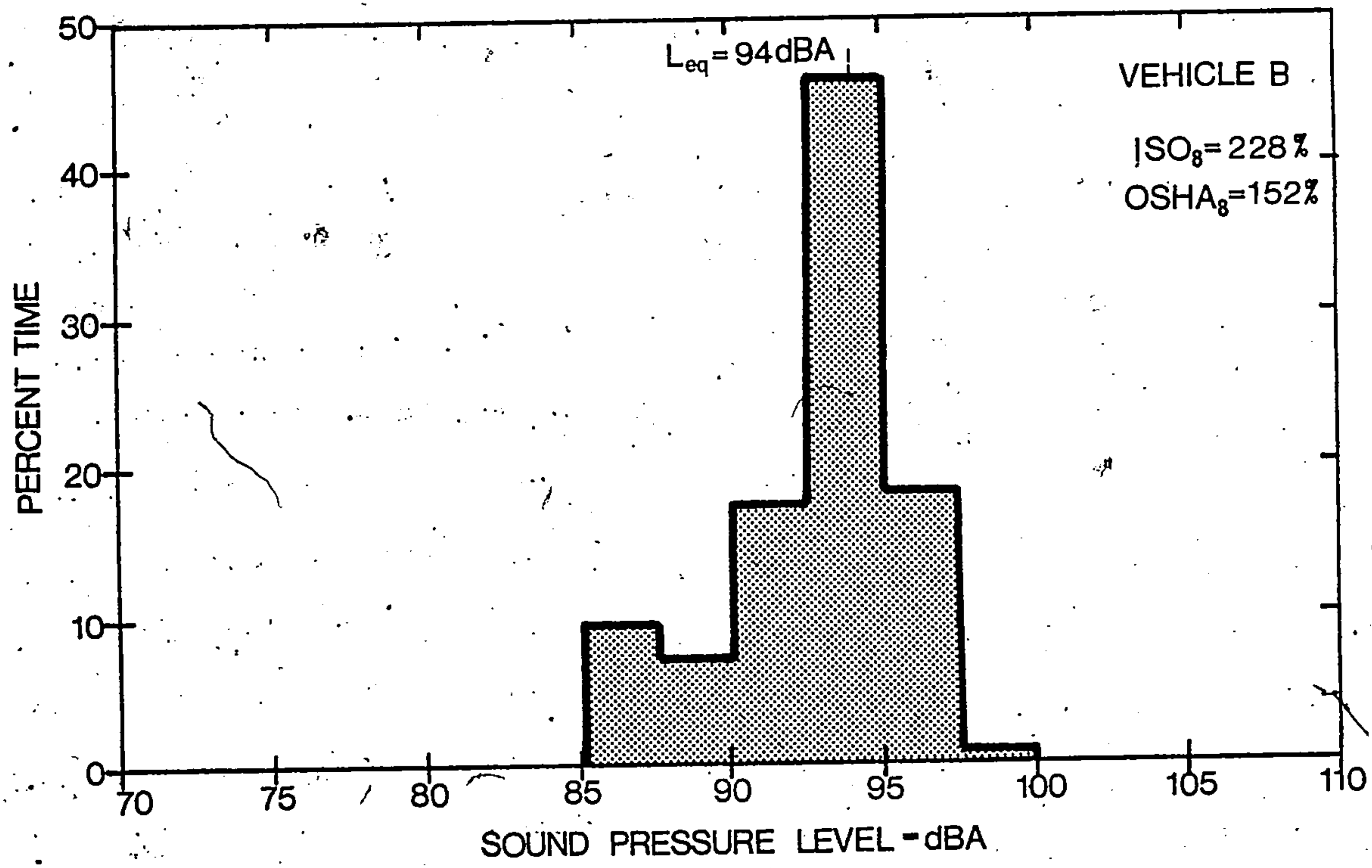

FIGURE 33 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE B

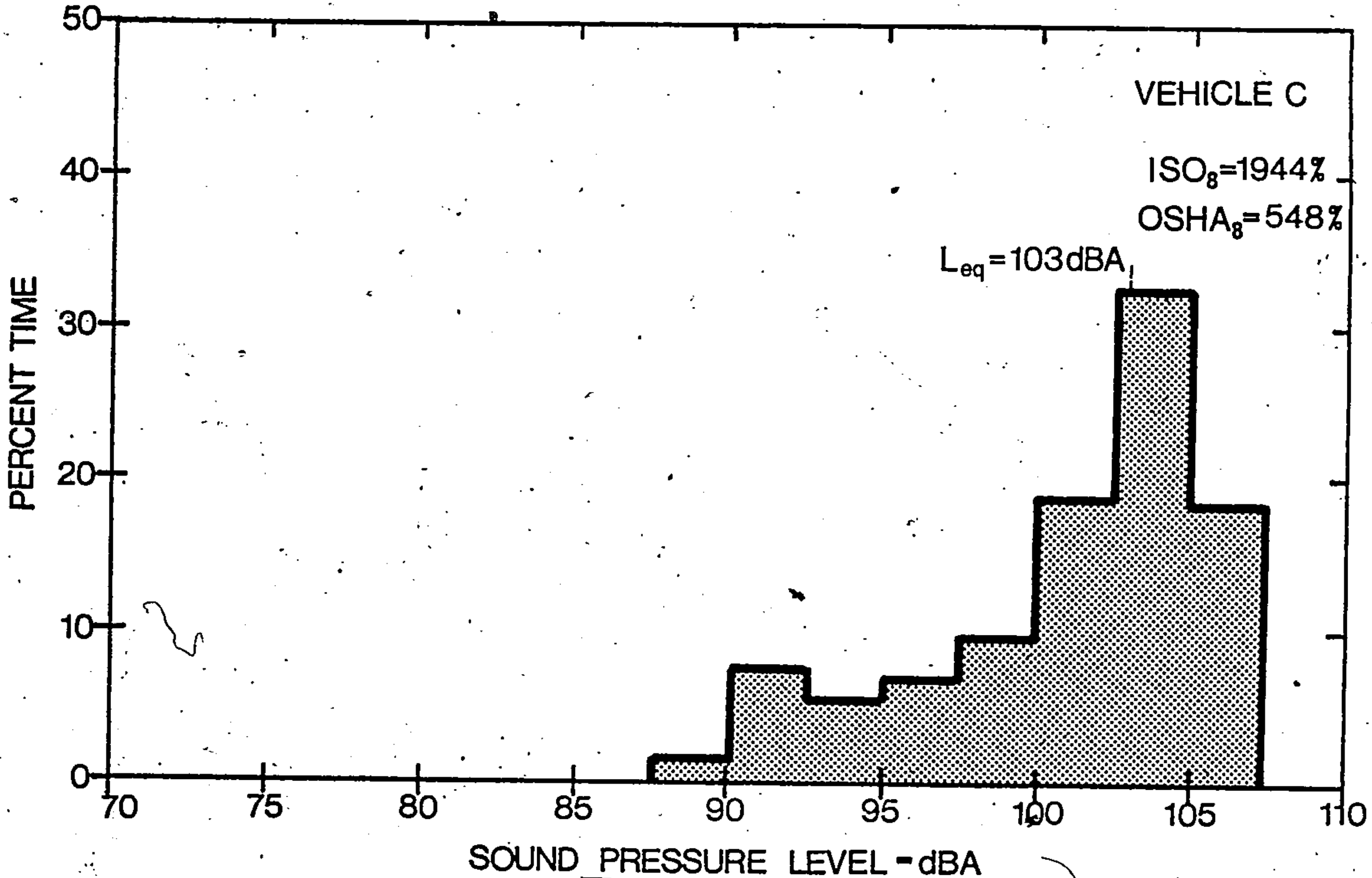

FIGURE 34 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE C

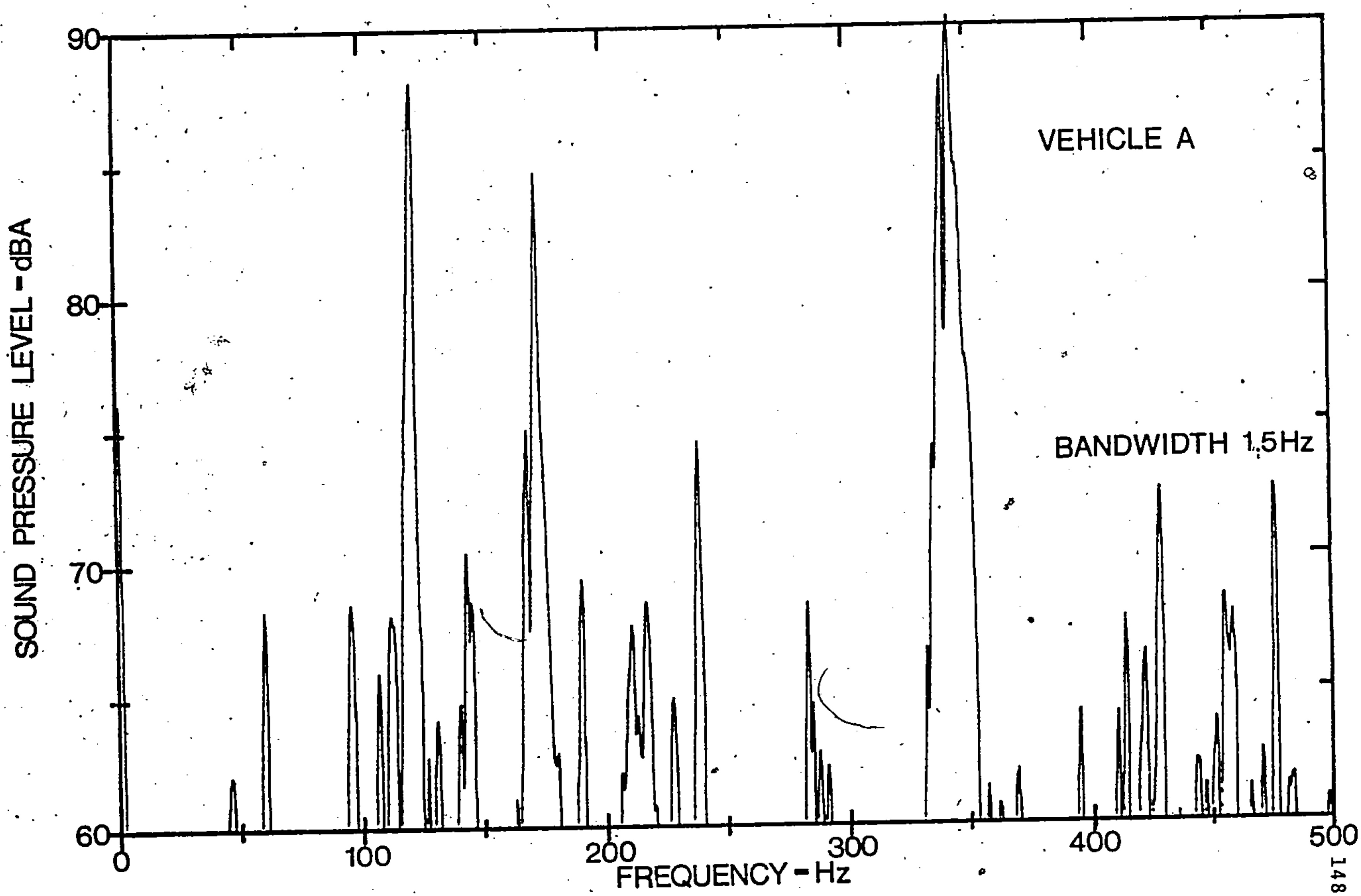

FIGURE 35 NARROW BAND ANALYSIS OF AT EAR SNOWMOBILE NOISE - 0 - 500 Hz

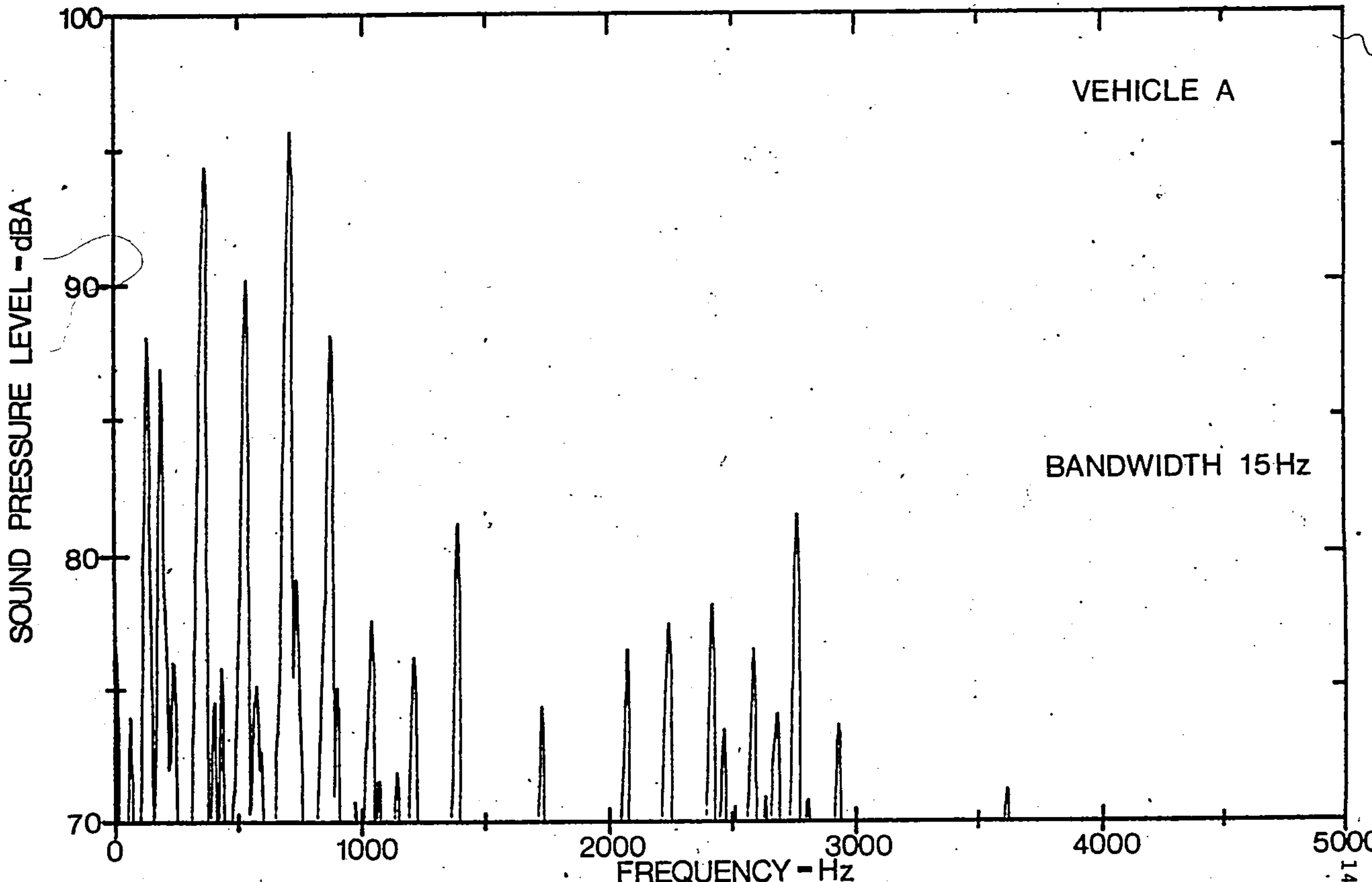

FIGURE 36 NARROW BAND ANALYSIS OF AT EAR SNOWMOBILE NOISE - 0 - 5000 Hz

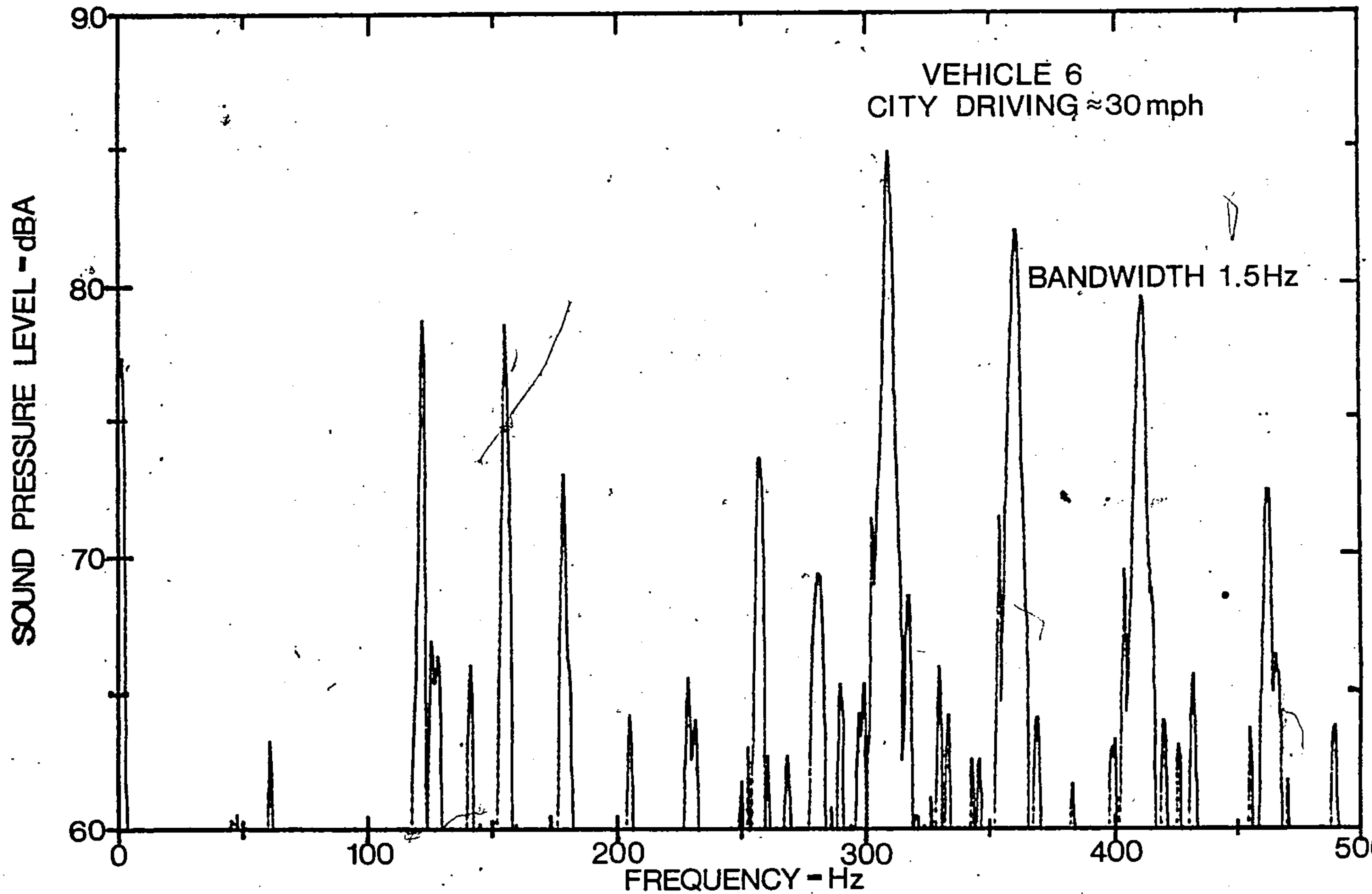

FIGURE 37 NARROW BAND ANALYSIS OF AT EAR MOTORCYCLE NOISE - 30 MPH - 0 TO 500 Hz

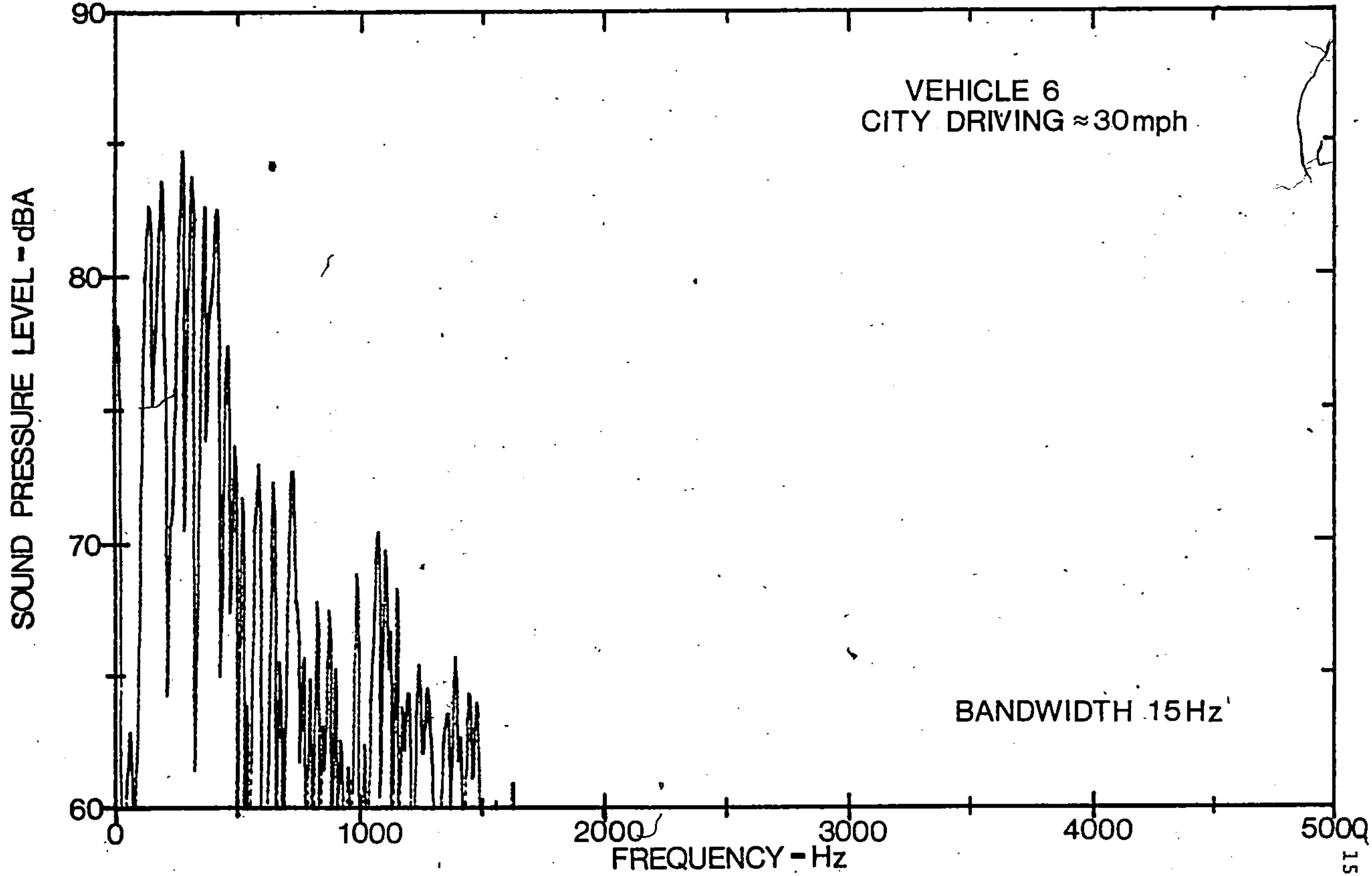

FIGURE 38 NARROW BAND ANALYSIS OF AT EAR MOTORCYCLE NOISE - 30 MPH - 0 TO 5000 HZ

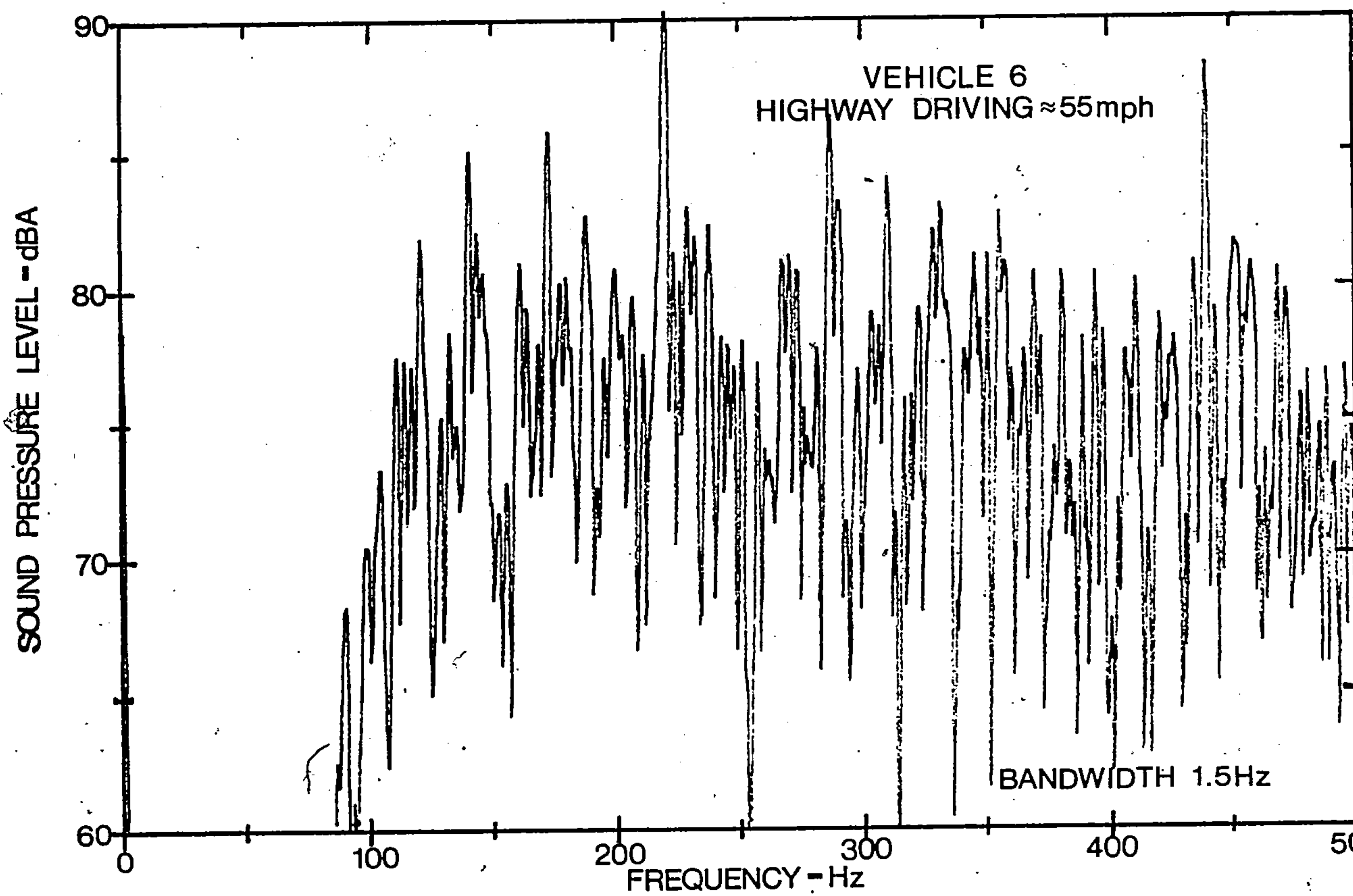

Figure 39 Narrow Band Analysis of At Ear Motorcycle Noise - 55 MPH - 0 to 500 Hz

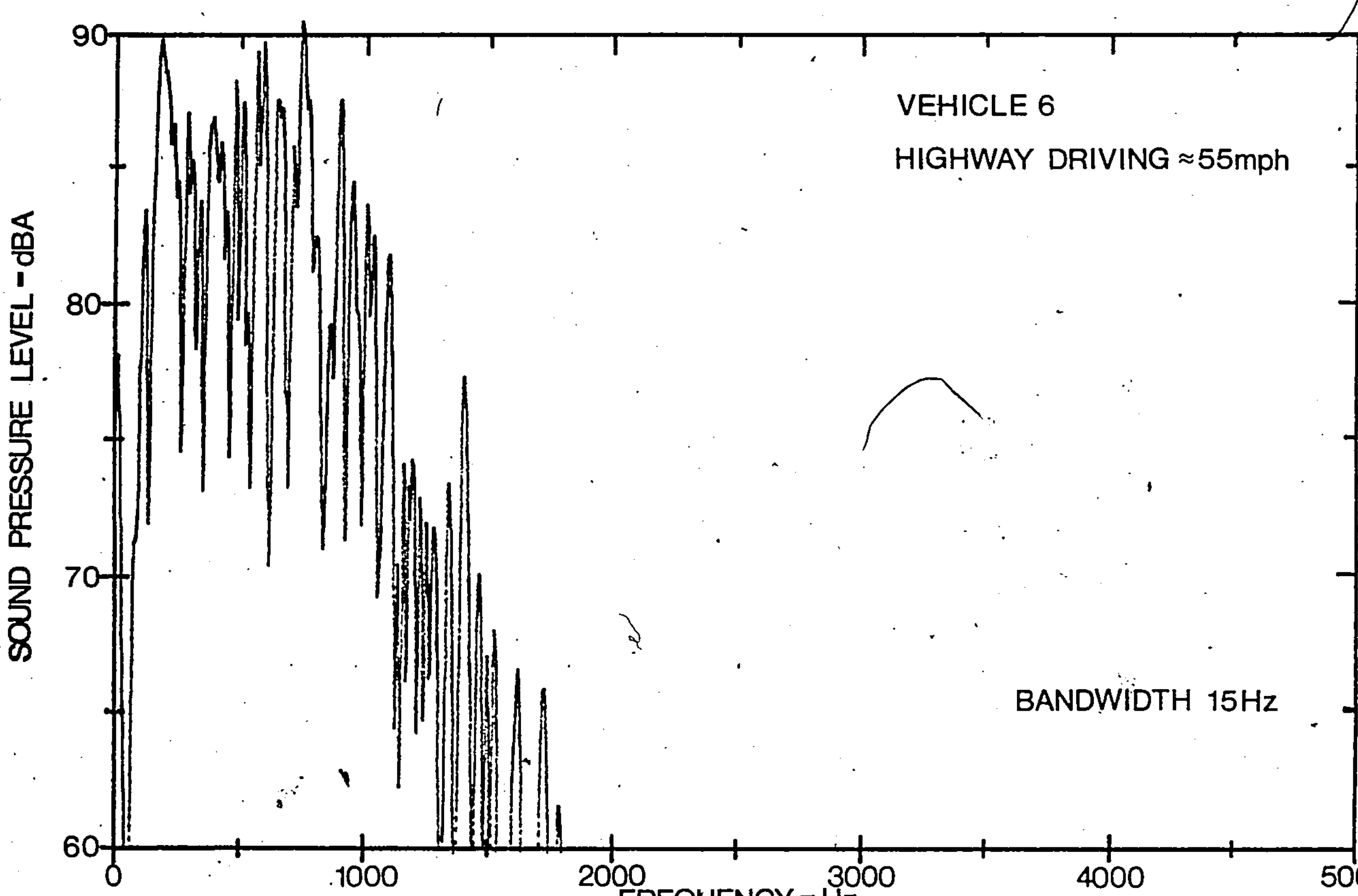

FIGURE 40 NARROW BAND OF AT EAR NOISE - 55 MPH - 0 - 5000 Hz

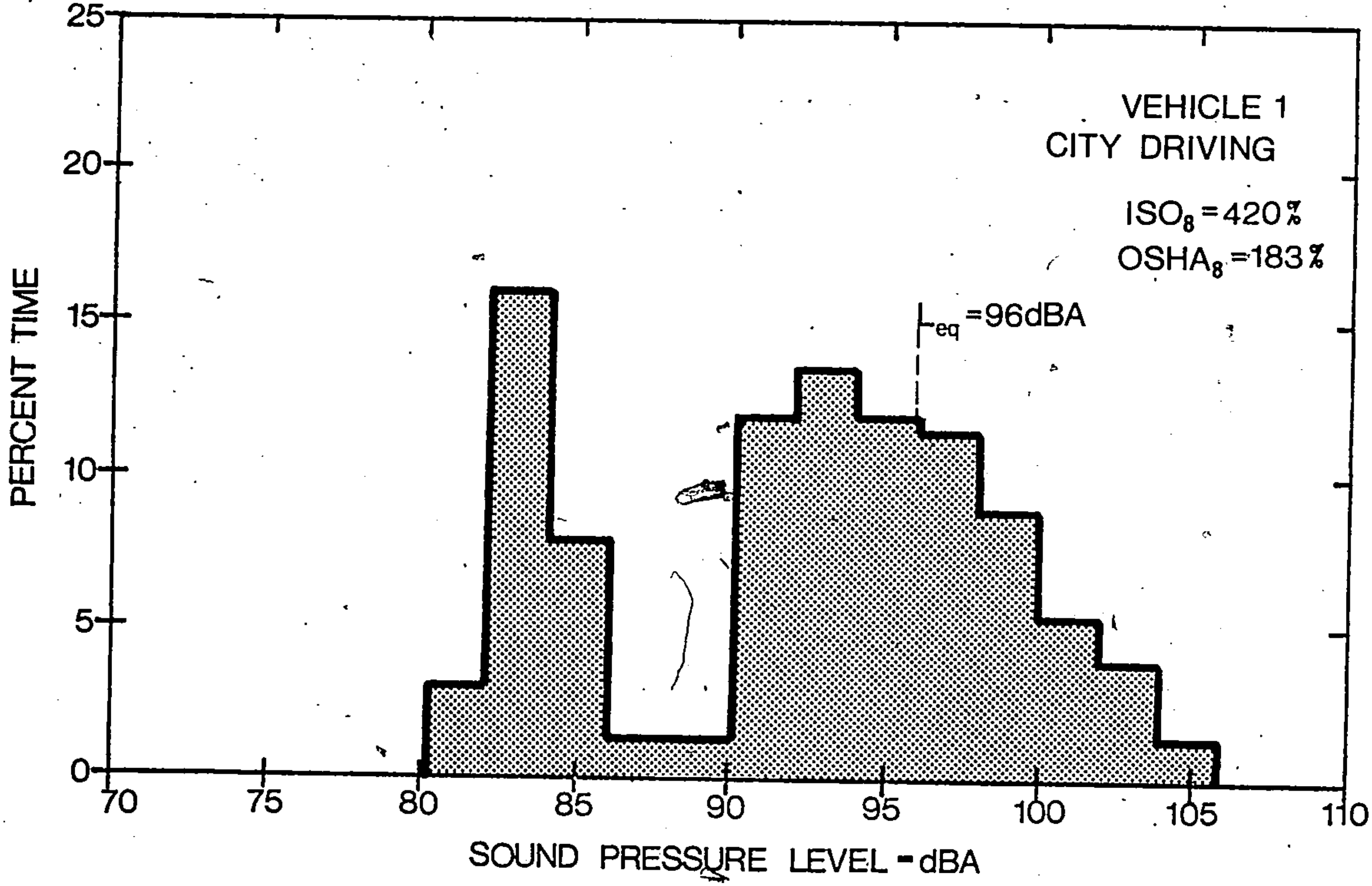

FIGURE 41 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 1 - CITY DRIVING

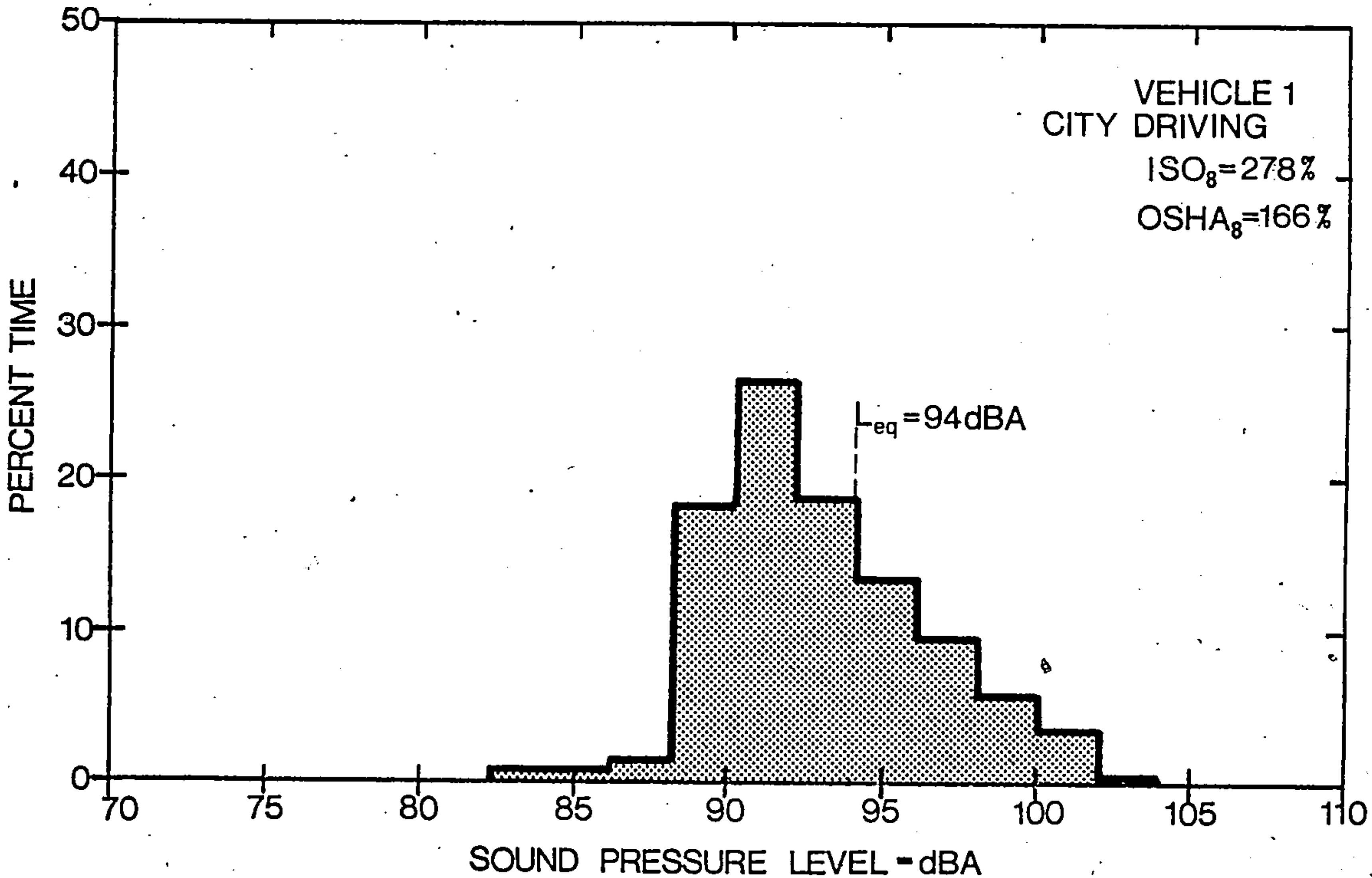

FIGURE 42 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 1 - CITY DRIVING

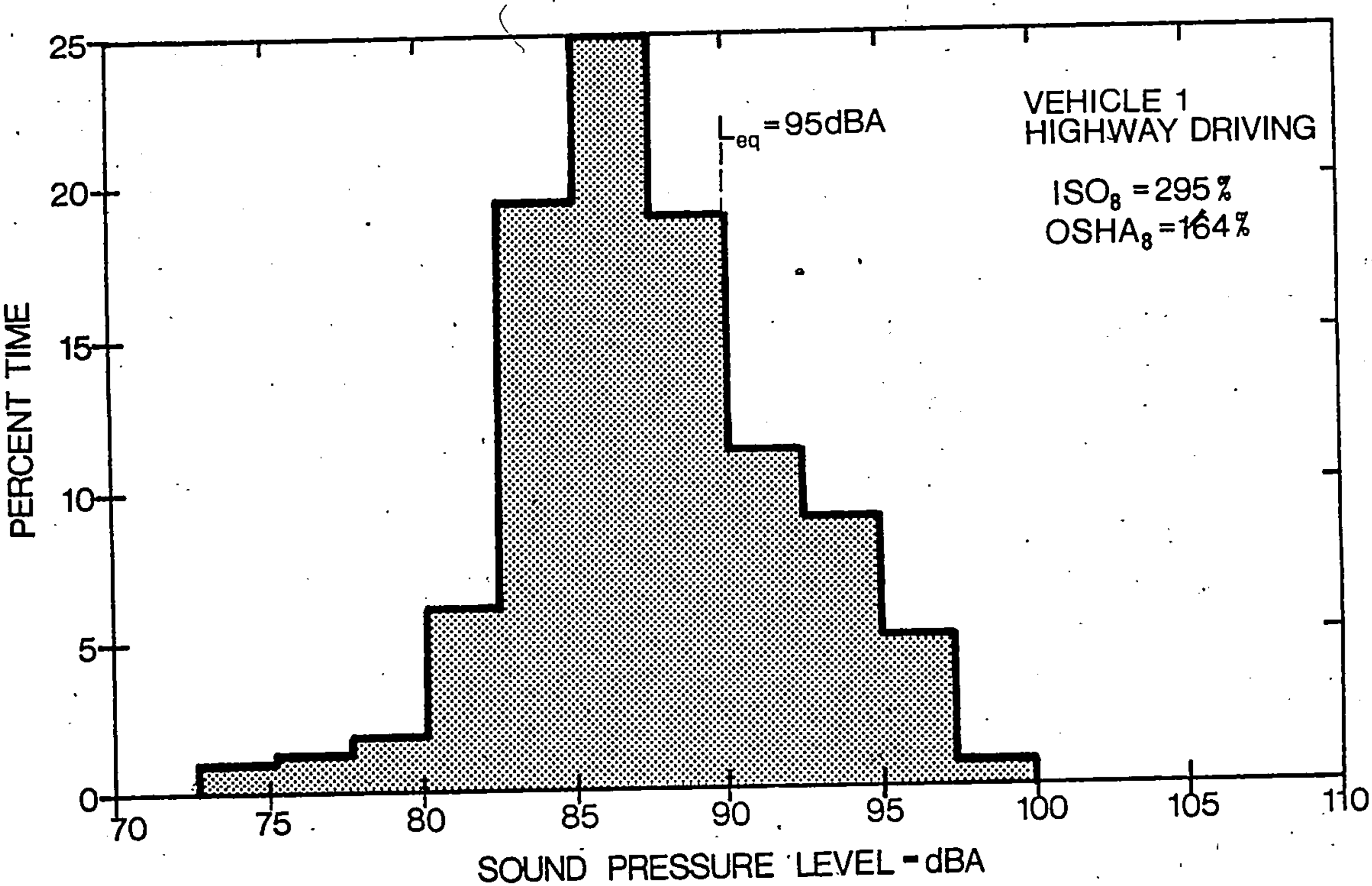

FIGURE 43 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 1 - HIGHWAY DRIVING

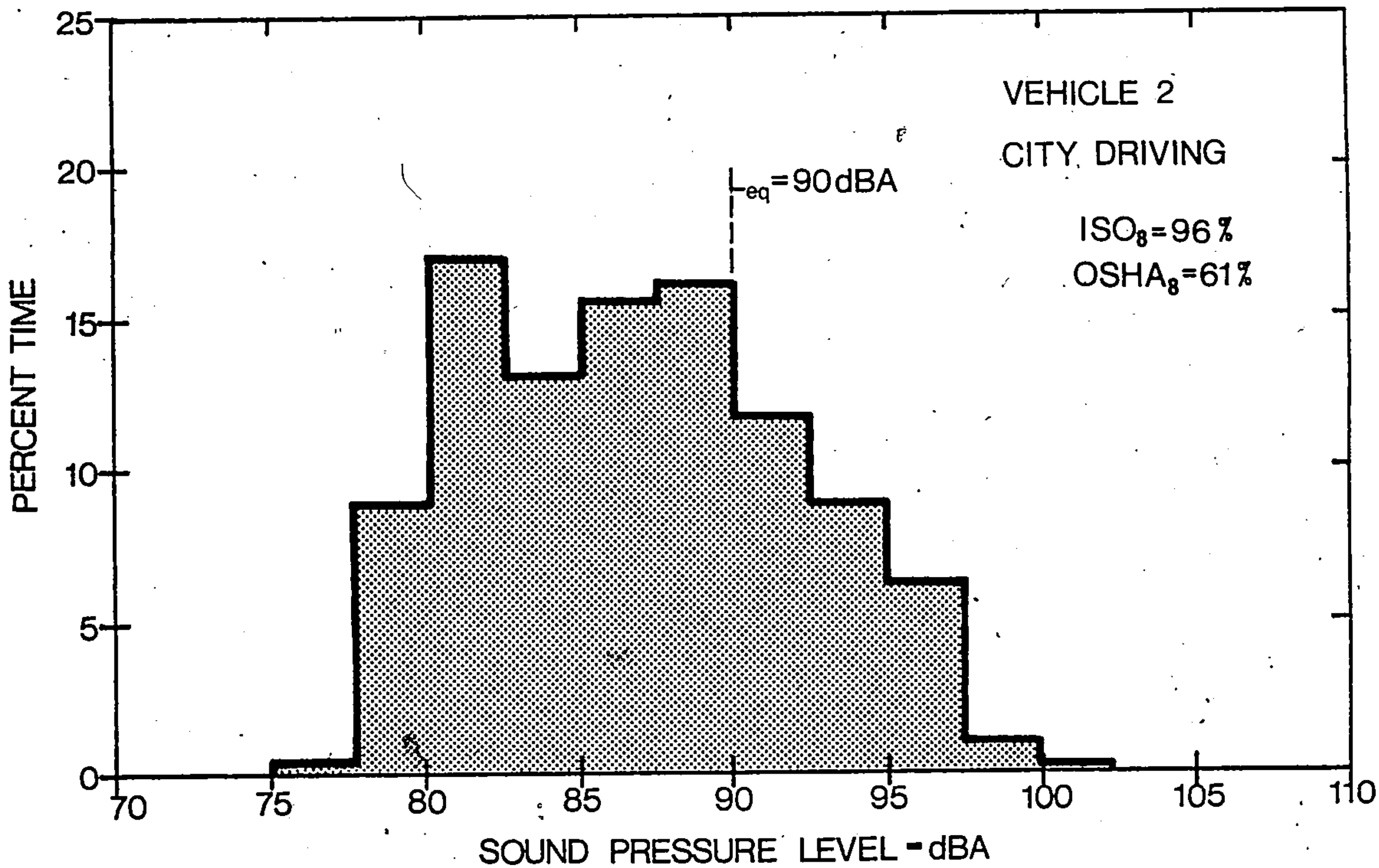

FIGURE 44 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 2 - CITY DRIVING

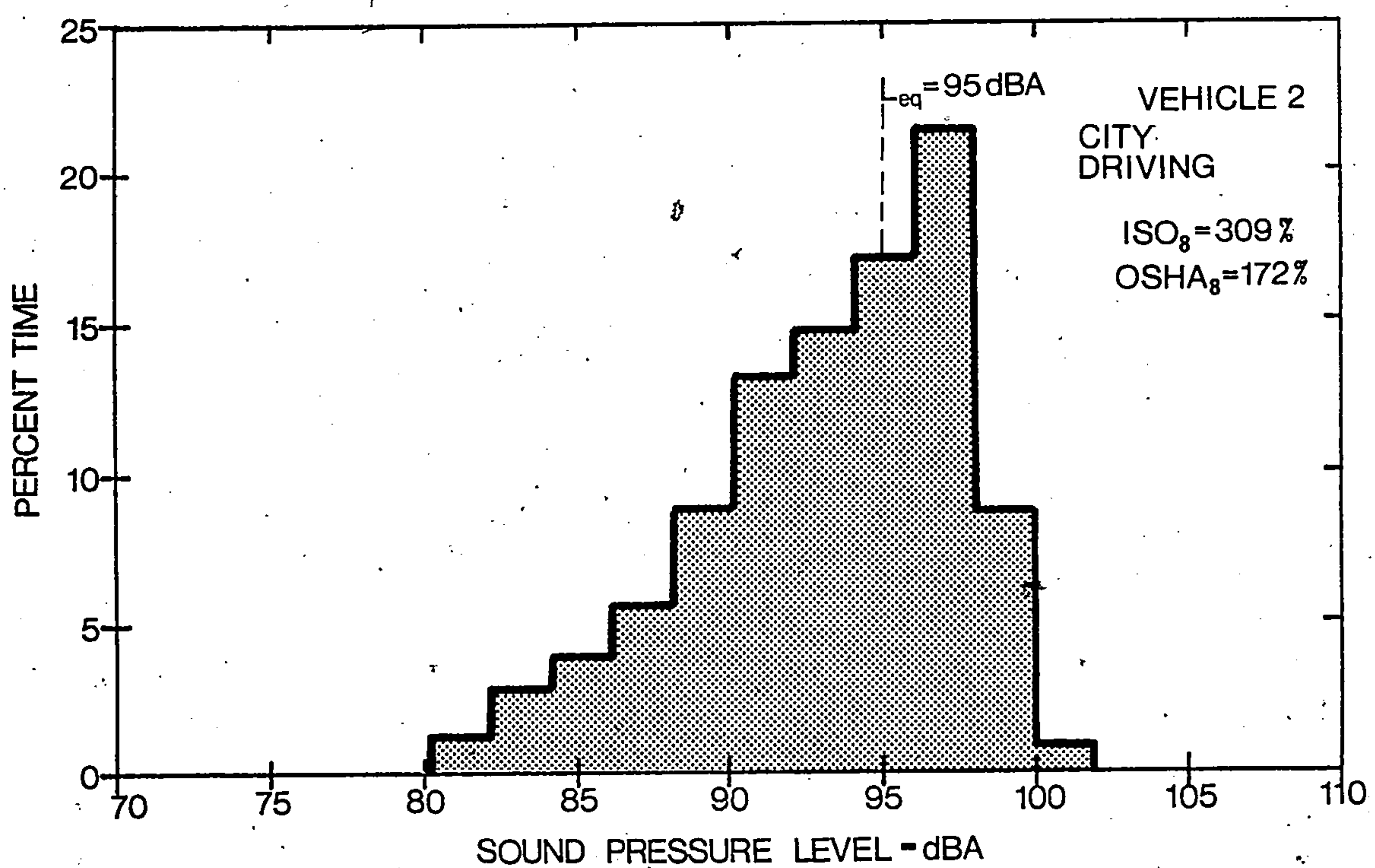

FIGURE 45 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 2 - CITY DRIVING

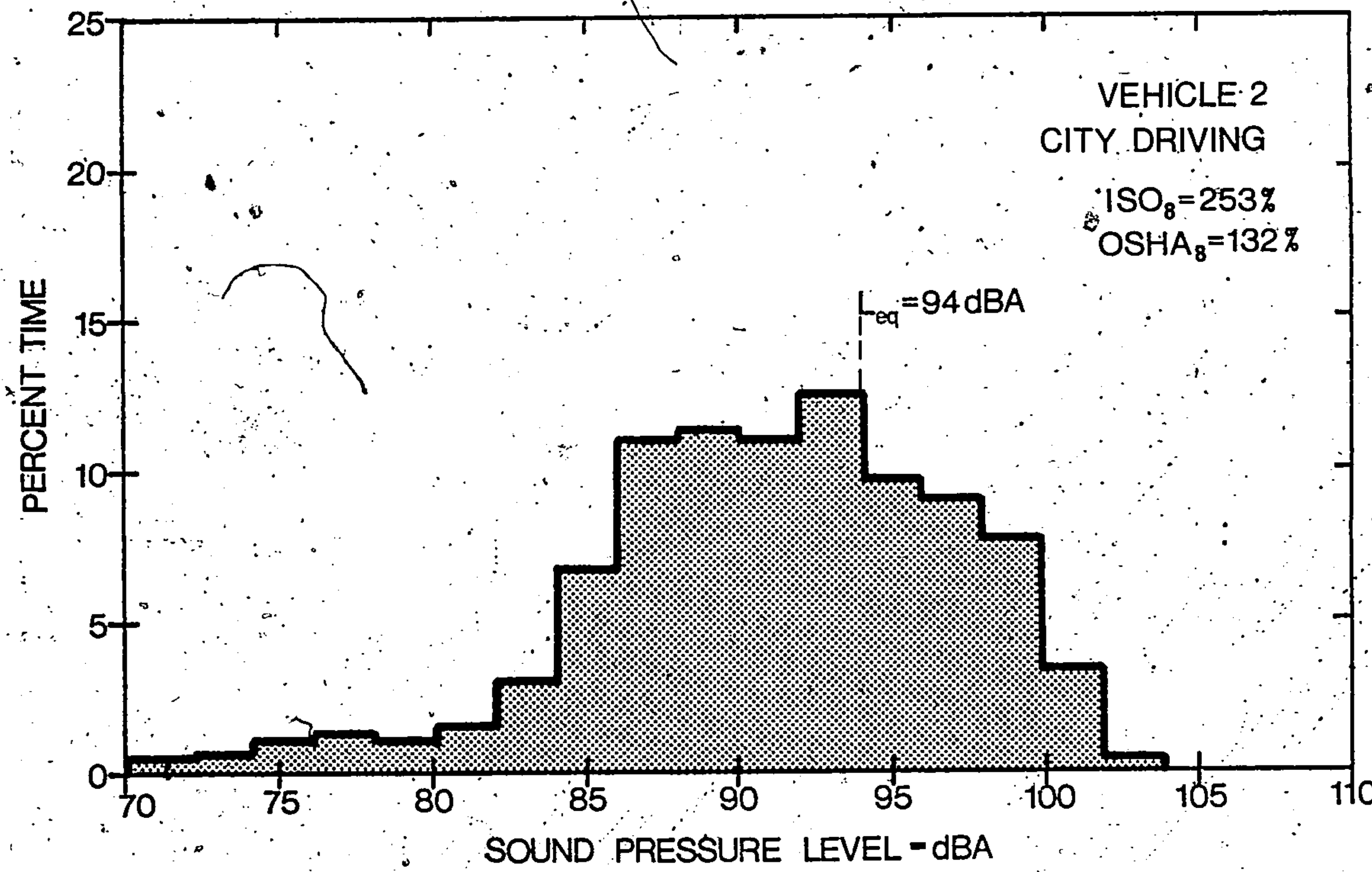

FIGURE 46 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 2 - CITY DRIVING

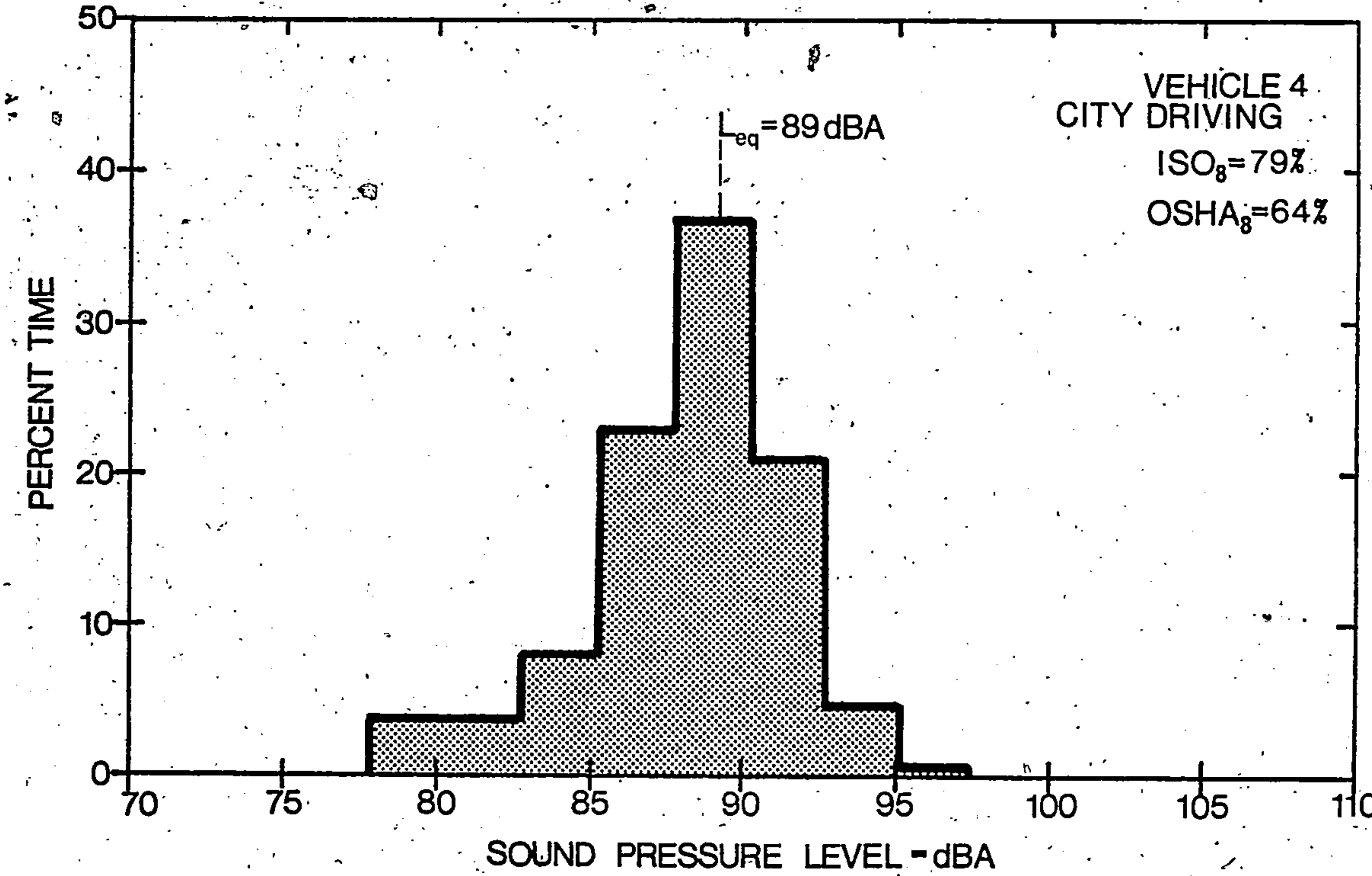

FIGURE 47 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 4 - CITY DRIVING

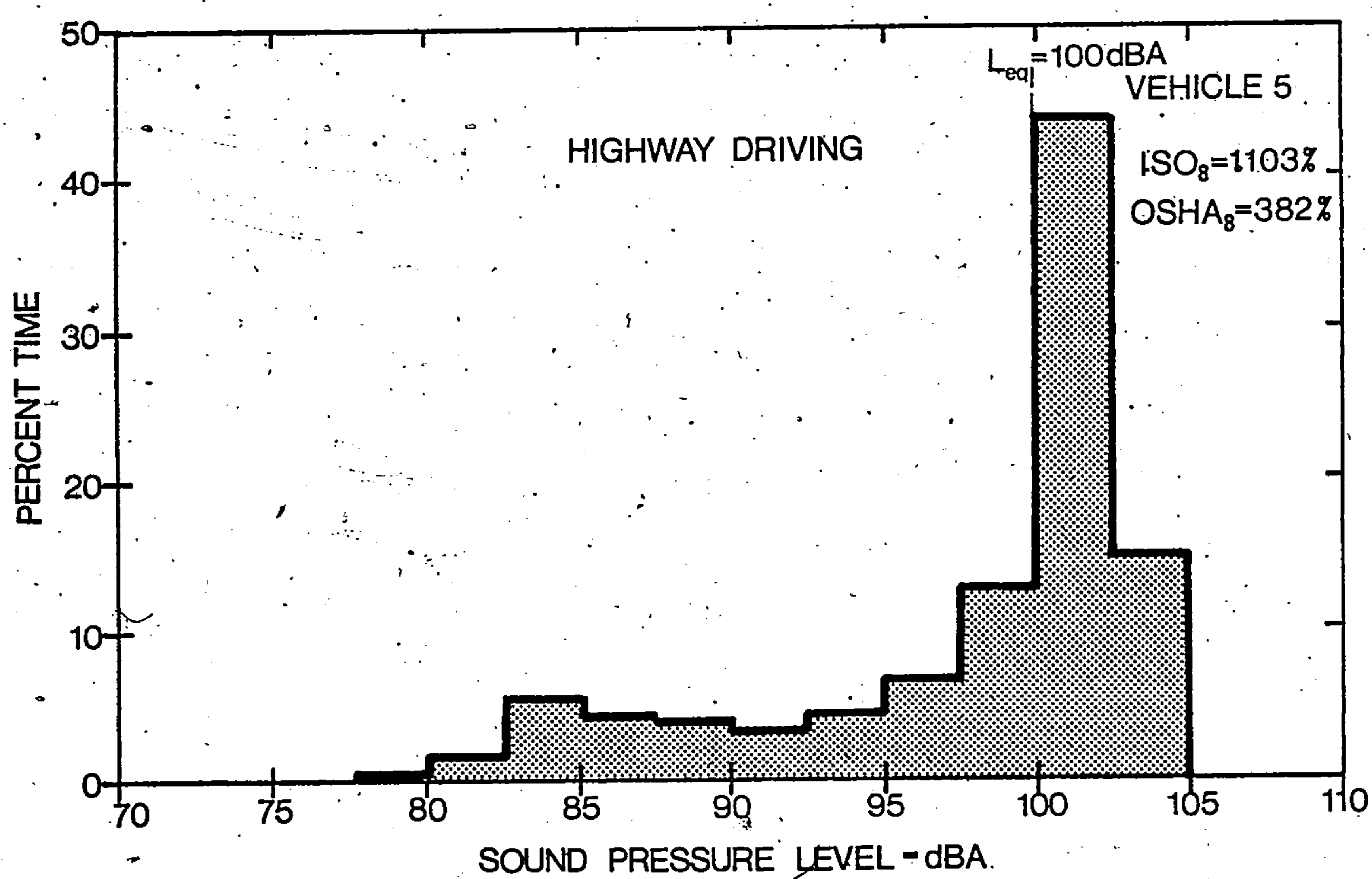

FIGURE 48 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 5 - HIGHWAY DRIVING

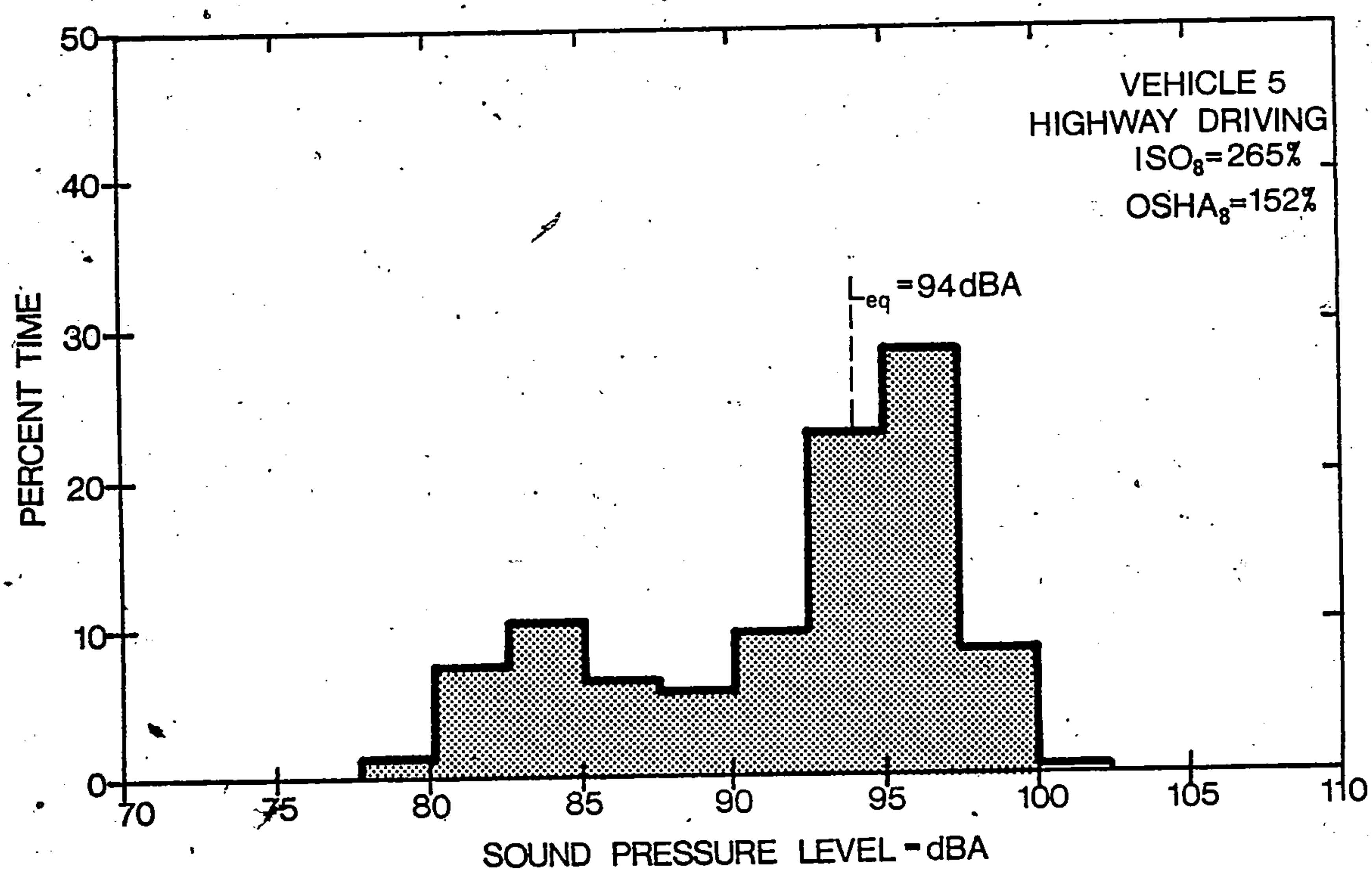

FIGURE 49 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 5 - HIGHWAY DRIVING

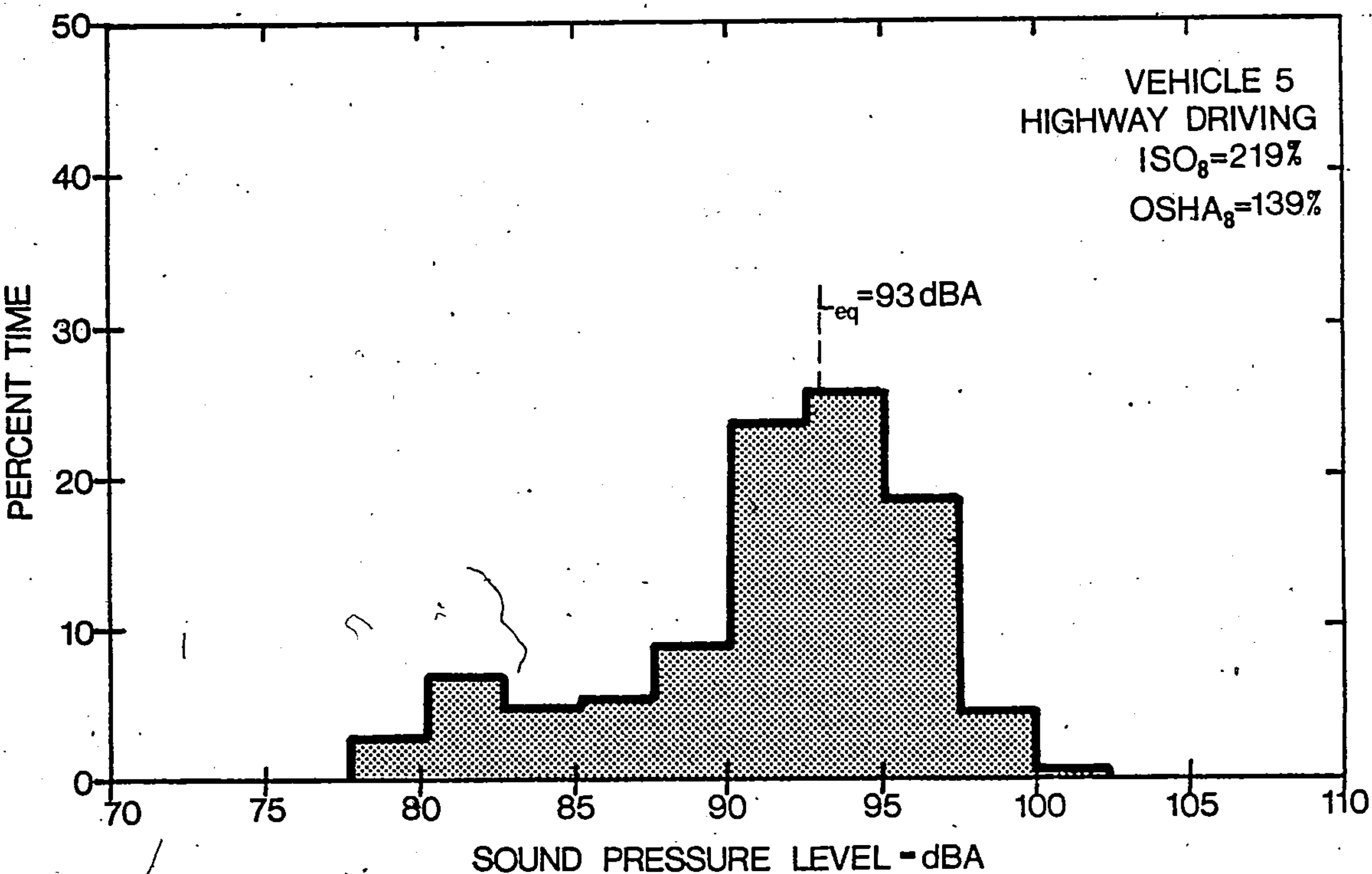

FIGURE 50 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 5 - HIGHWAY DRIVING

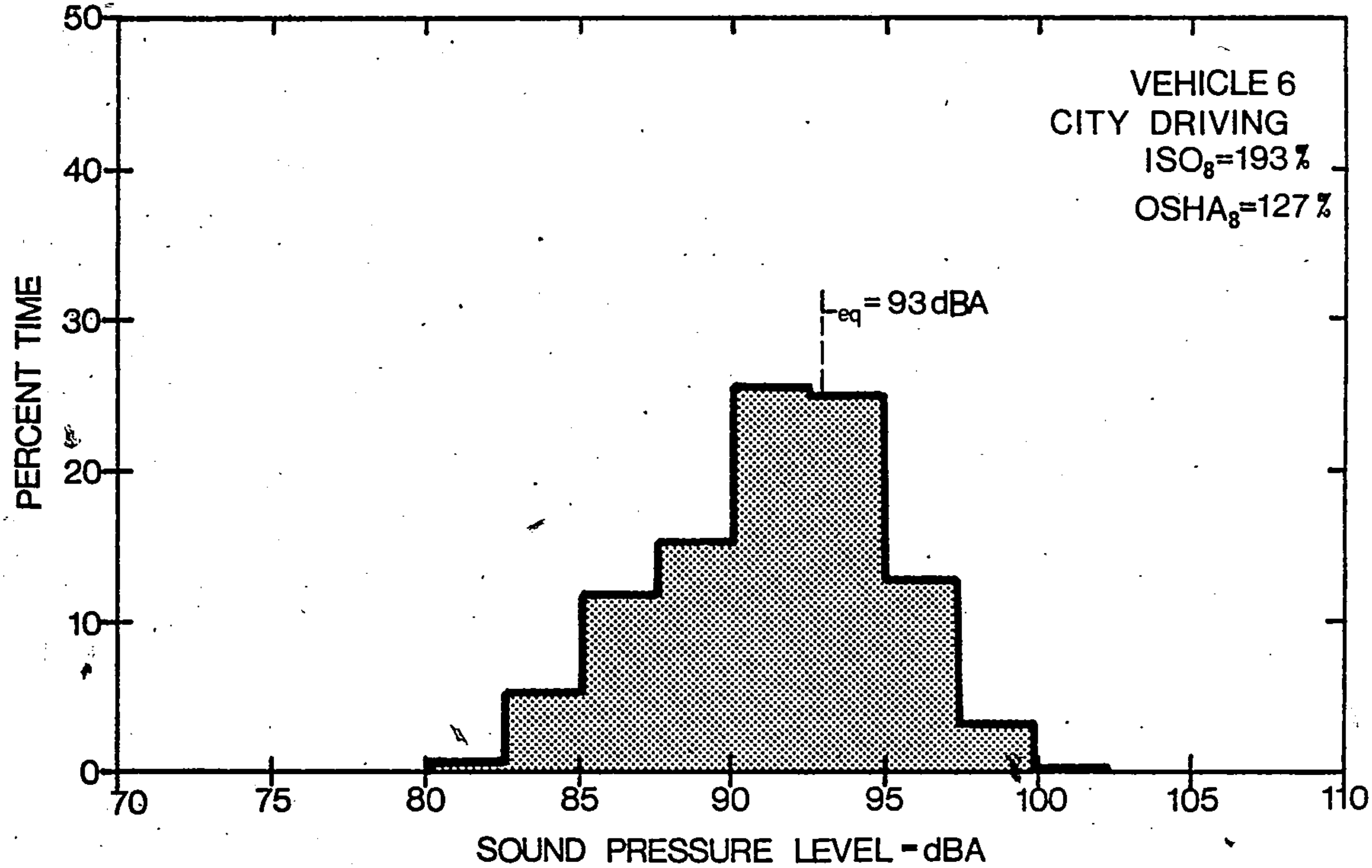

FIGURE 51 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 6 - CITY DRIVING

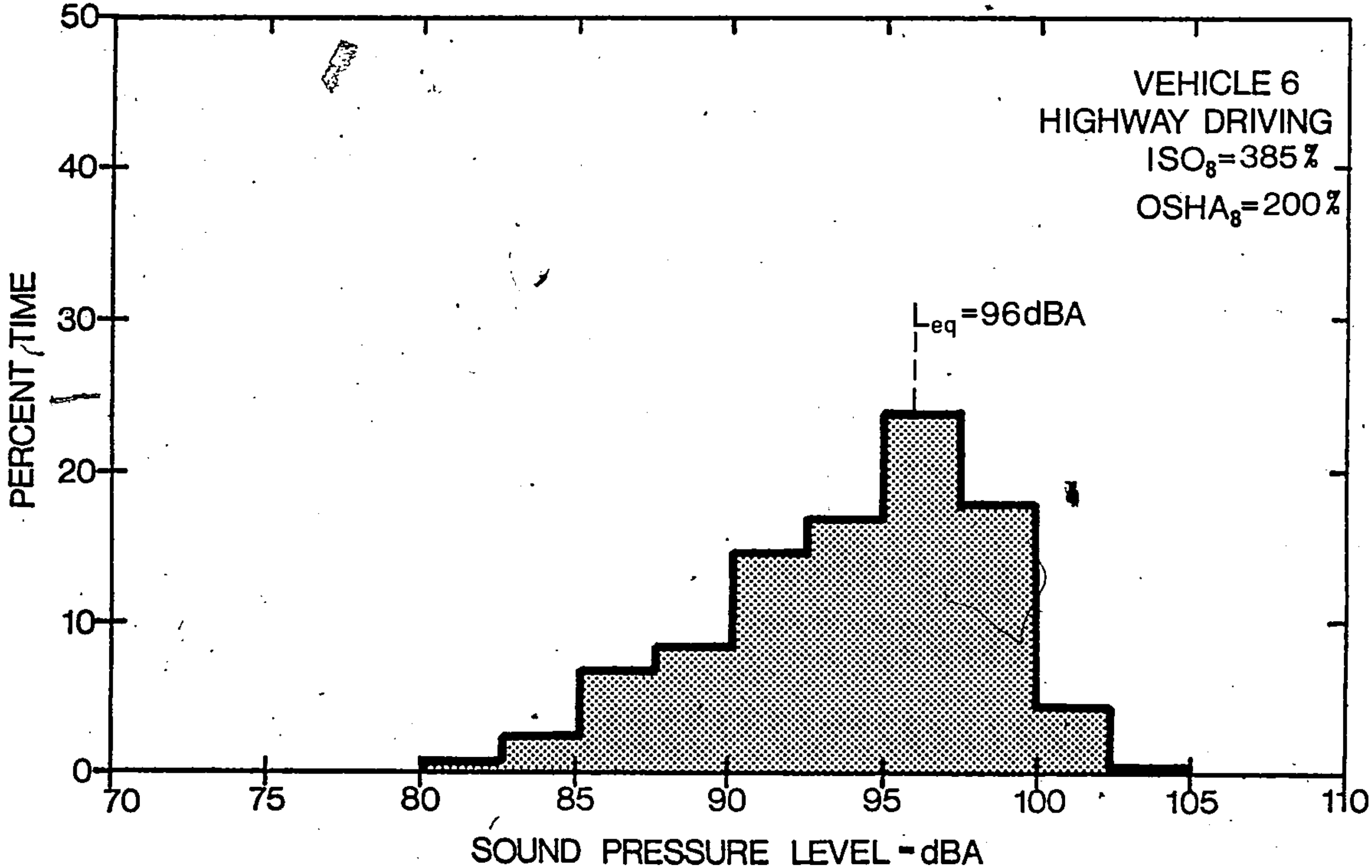

FIGURE 52 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 6 - HIGHWAY DRIVING

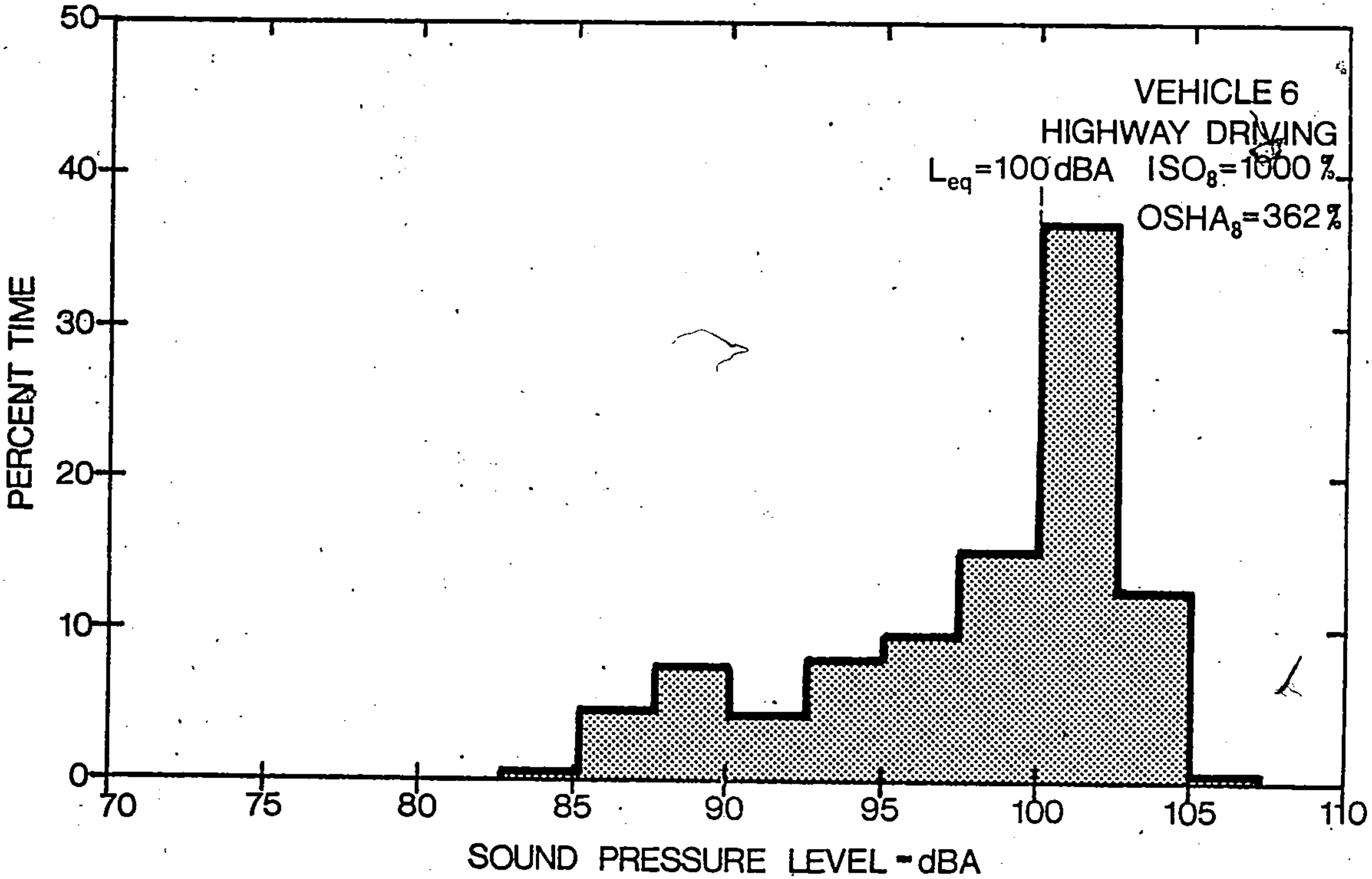

FIGURE 53 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 6 - HIGHWAY DRIVING

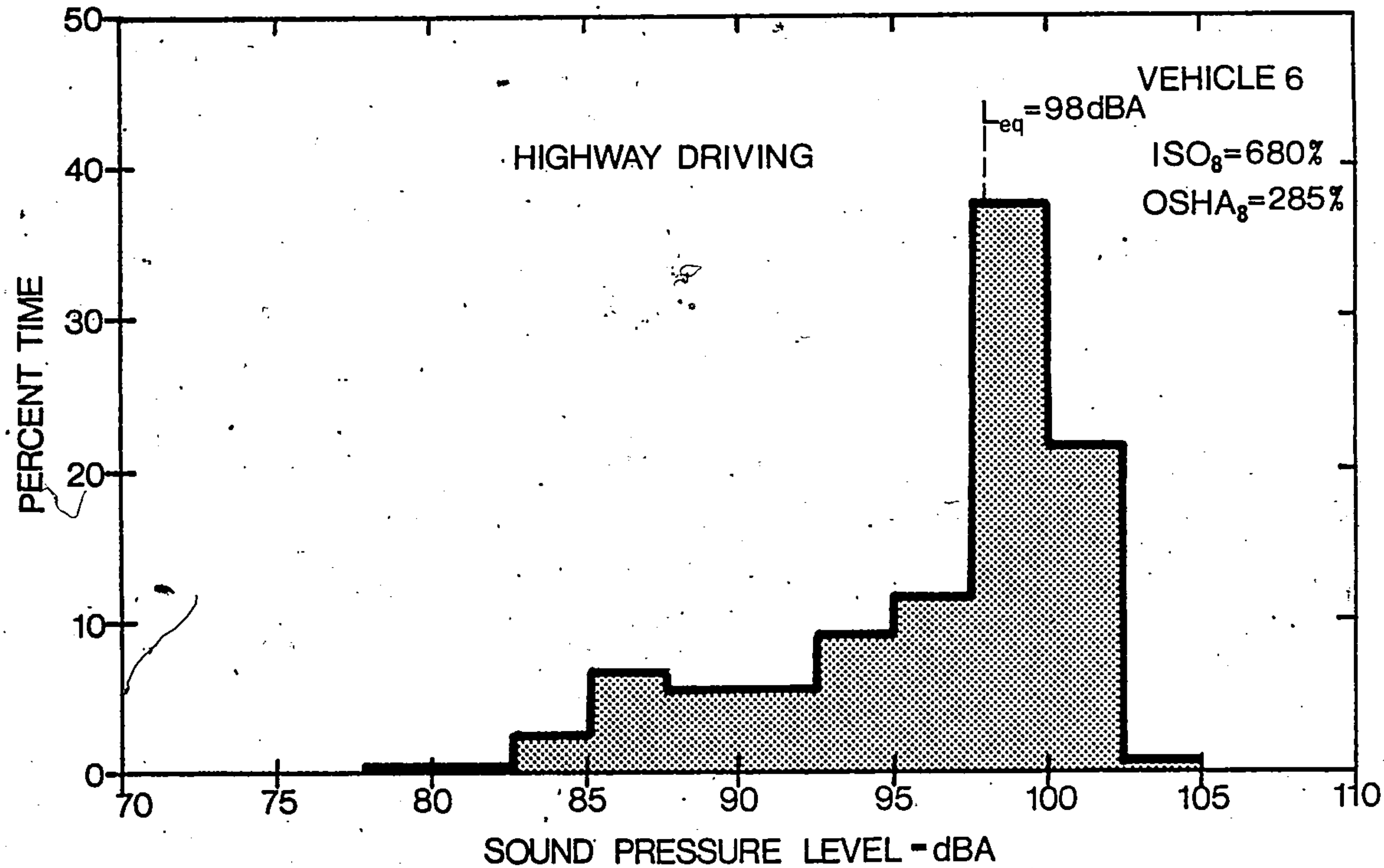

FIGURE 54 HISTOGRAM OF AT EAR NOISE LEVELS FOR VEHICLE 6 - HIGHWAY DRIVING

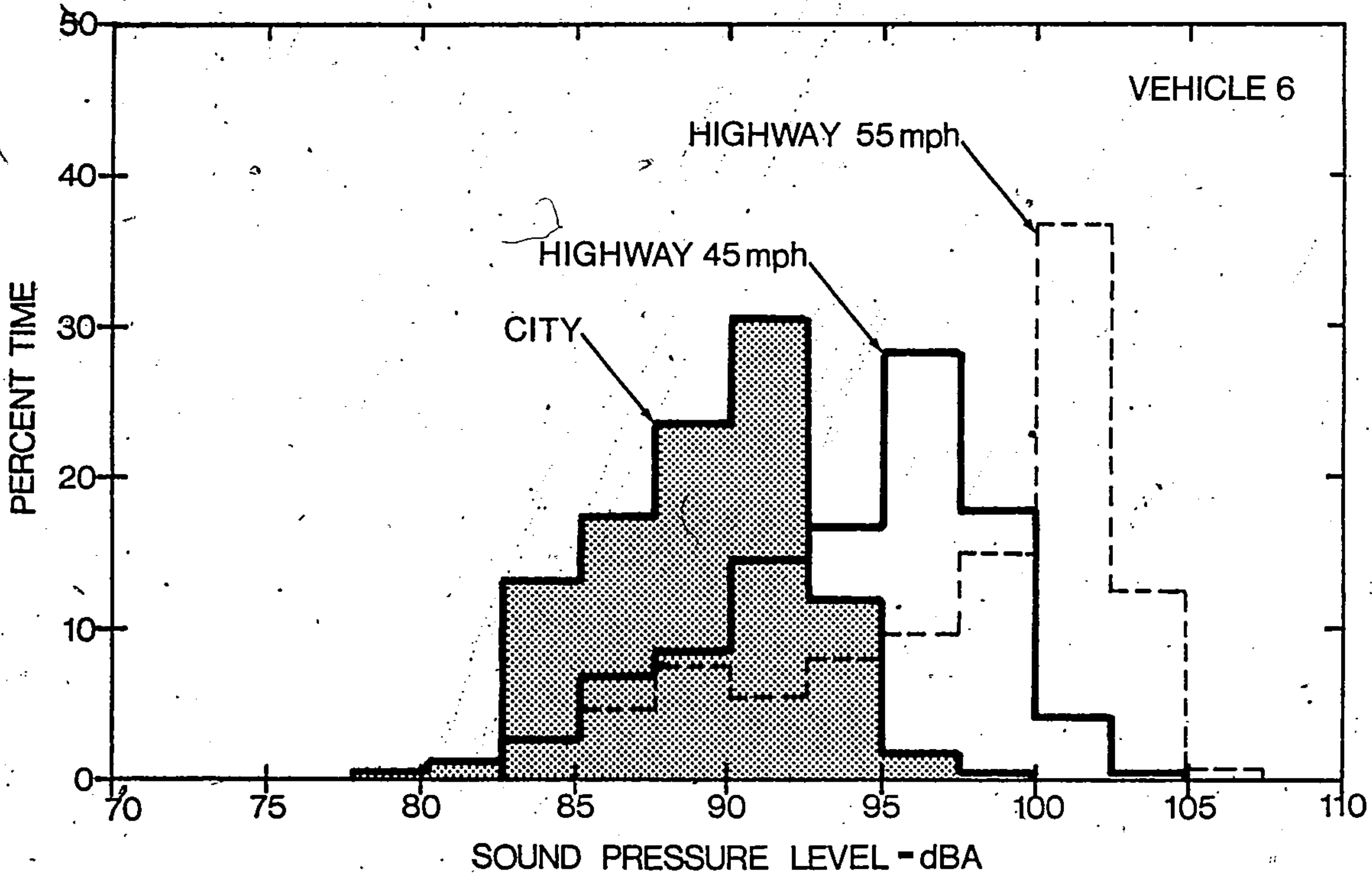

FIGURE 55 EFFECT OF SPEED ON AT EAR NOISE LEVELS - VEHICLE 6

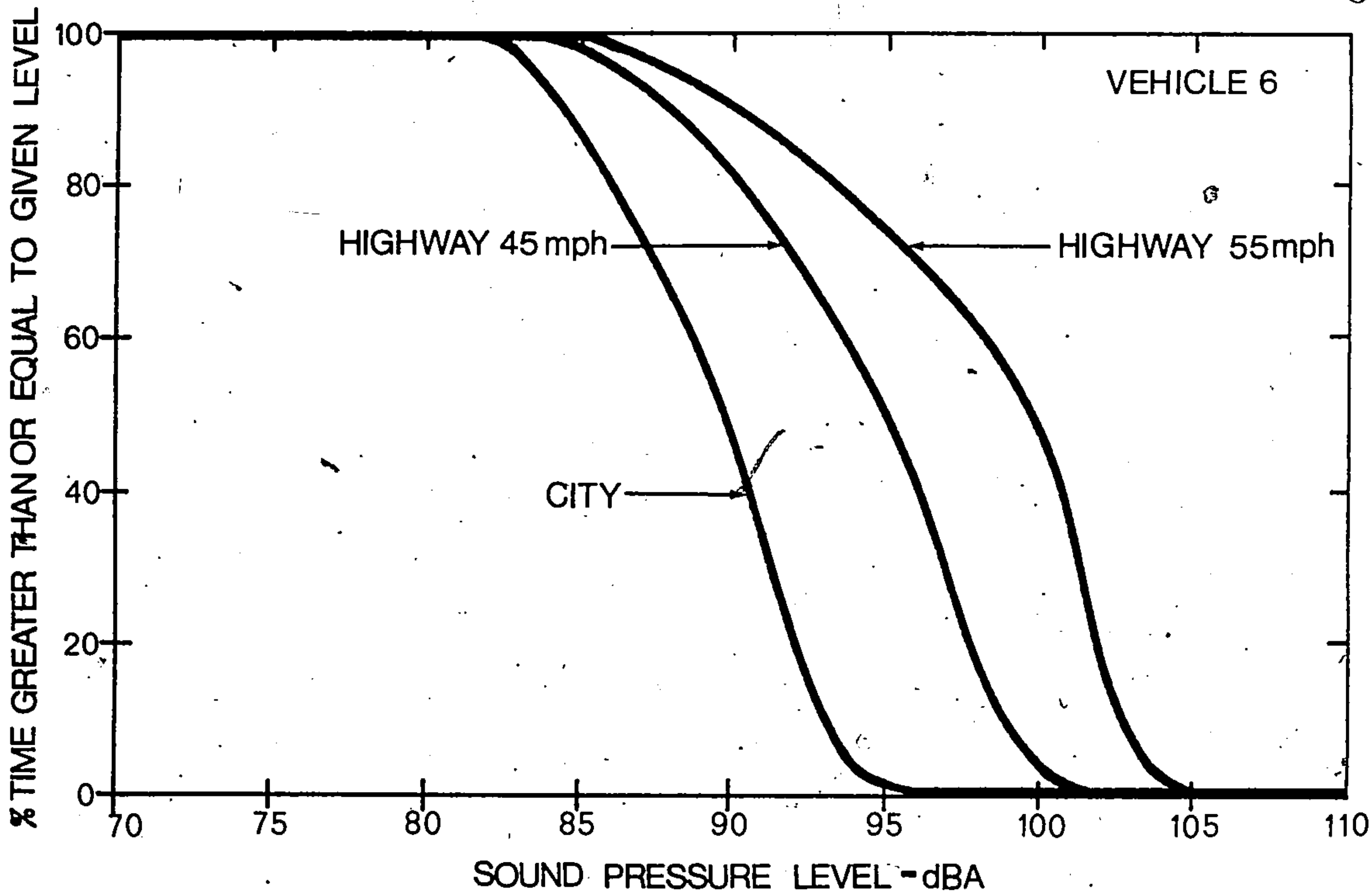

FIGURE 56 CUMULATIVE DISTRIBUTION OF NOISE LEVELS FOR VARIOUS SPEEDS - VEHICLE 6

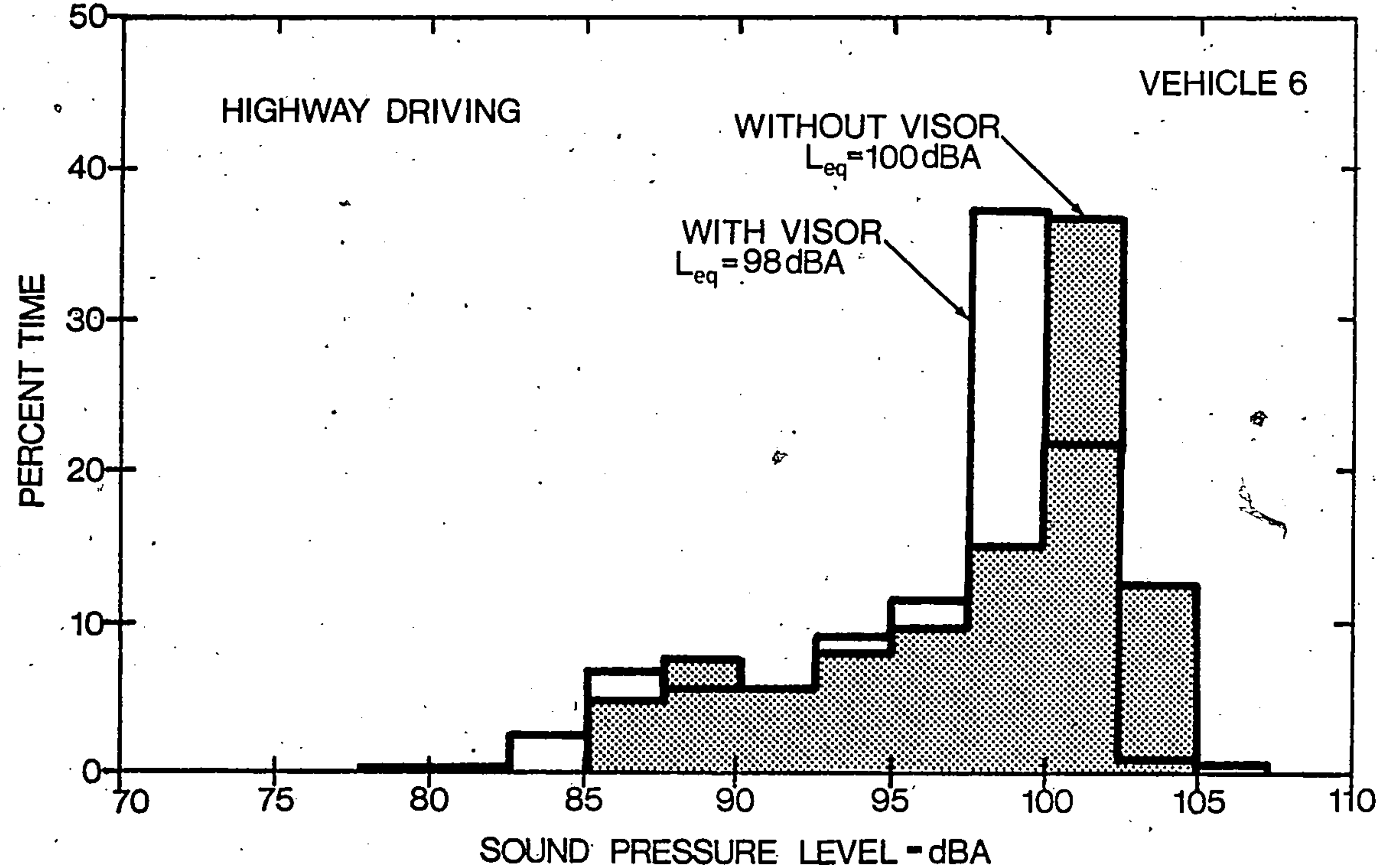

FIGURE 57 EFFECT OF VISOR ON AT EAR NOISE LEVELS - VEHICLE 6

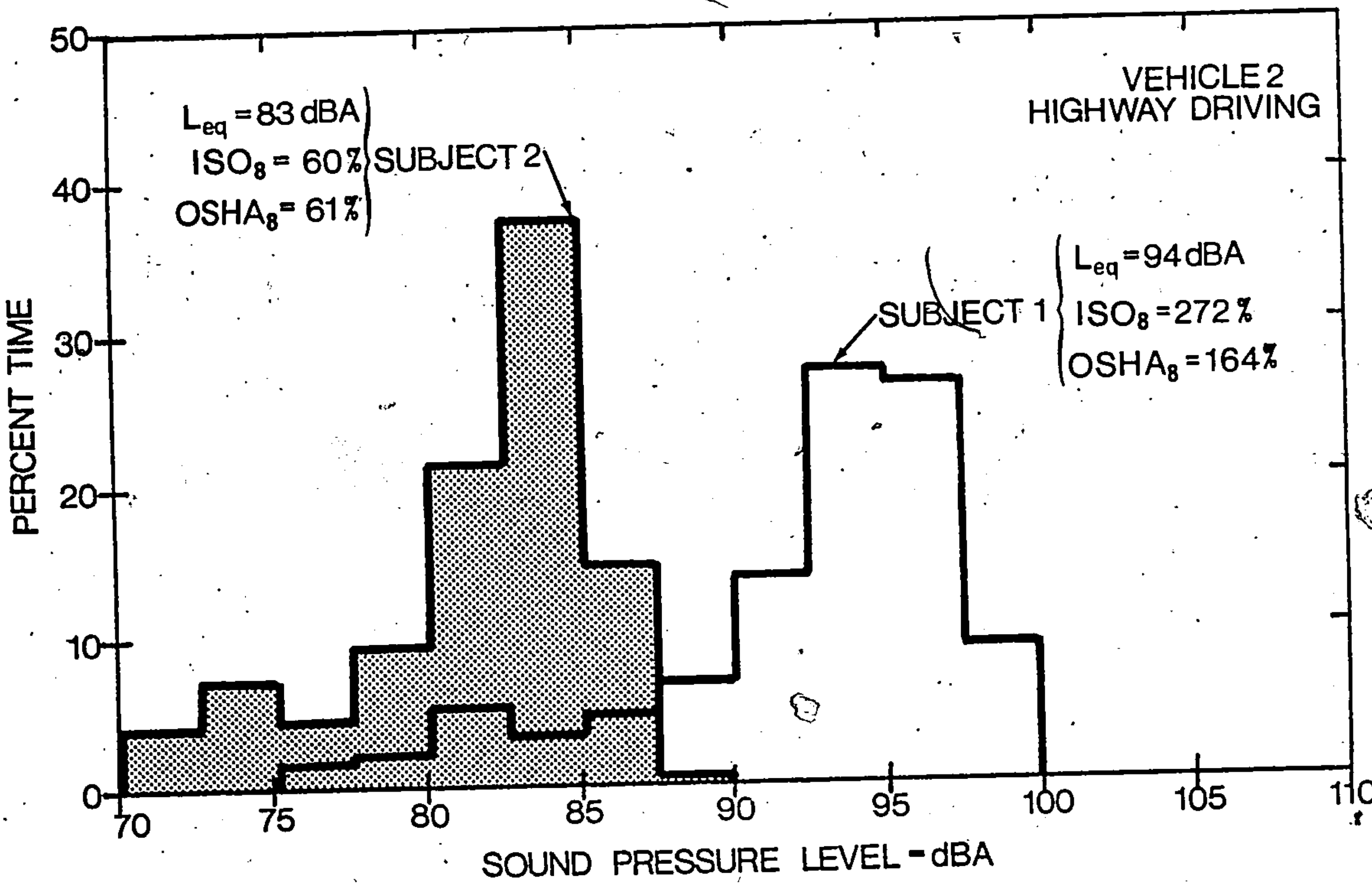

FIGURE 58 EFFECT OF SUBJECT ON AT EAR NOISE LEVELS - VEHICLE 2

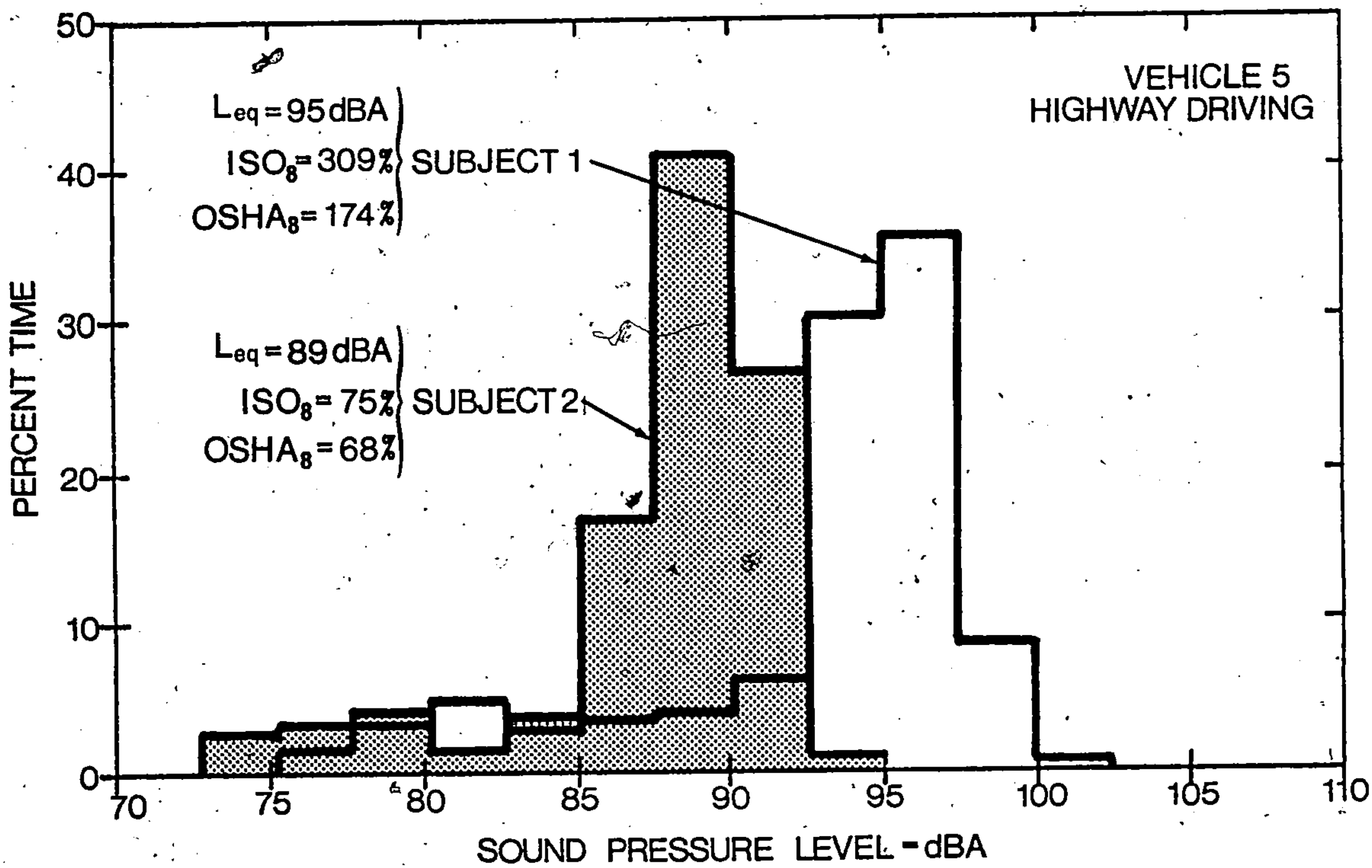

FIGURE 59 EFFECT OF SUBJECT ON AT EAR NOISE LEVELS - VEHICLE 5

SUBJECT		NO HELMET		SMALL HELMET						MEDIUM HELMET						LARGE HELMET						X-LARGE HELMET					
				ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR	
		FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR
1	EAR BUG	+2	-2	▲ -2	-3	-2	-4	0	-2							-2	-5	-1	-5	+2	-1.5						
	DOSIMETER	+4.7	-2.4	0	-4.7	- .5	-5.8	0	-5							+2	-4.5	+2.5	-5.5	+4.7	-3.2						
2	EAR BUG	+ .5	-2.5							-7	-5	-7	-5	-5	-3.5	▲ -6	-5	-6	-5	-4.5	-4	-2	-1.5	-1	-1	0	-1
	DOSIMETER	+3	-3.5							-2.2	-4	-3	-4	-1	-2.5	-1	-6	-2	-6	-1	-4.3	0	-3	- .5	-3	+1	-3
3	EAR BUG	+3.5	- .5	-1	-3	-1.5	-2.5	-1	-2	▲ -1	-1	+3	+1	+3.5	+3	+4	-	+3	-2	+1	0						
	DOSIMETER	+4	-2.5	+ .5	-5	- .5	-5	+ .5	-3	+4.5	-1.5	+4	-2	+5.2	+1.5	+ .5	-5	+ .5	-4.5	+1	-4						
4	EAR BUG			▲ -6	-9	-5.5	-9.5	-4	-8	-6	-9	-6	-9.5	-5	-8	-4	-10	-4	-7	-2	-5						
	DOSIMETER			-1	-8.5	-1.5	-9	- .5	-6	-1.7	-8.5	-1.7	-7	0	-5.5	- .5	-11	- .5	-6.5	+1.3	-3.5						
5	EAR BUG	-3	-5	▲ -6	-9	-10	-6	-8	-6	-9.5	-5	-9	-6	-8	-4.5	-9.5	-6.5	-8.5	-6.5	-7.5	-6.5						
	DOSIMETER	+1.5	-5.5	-6	-5.5	-7	-7.4	-7.4	-5.5	-3	-5.5	-3	-6	-3	-5	-6	-6	-7.4	-6	-6	-5.6						
6	EAR BUG	-5	-10							-7.5	-7	-7.5	-9	-5.5	-7	▲ -10	-9.5	-9	-9	-8	-8.5	-10	-8.5	-10	-8	-8.5	-7
	DOSIMETER	+1	-5							+ .5	-5.5	0	-4	+1	-2.4	-1	-7.4	-1	-6	0	-4	0	-4	-1	-5.5	+1	-4
7	EAR BUG	0	-3.5							-4.5	-3.5	-5.5	-4	-3	-3	▲ -5	-4.5	-6.5	-5	-4.5	-4	-2.5	-2.5	-2.5	-3	-1.5	-2.5
	DOSIMETER	- .5	-7							-1.5	-7.4	-3	-7.4	- .4	-5	-5	-7.4	-4.5	-9	-3	-7	-4	-6	-3	-6	-1	-5.5
8	EAR BUG	+1	0							-1.5	-2.5	-1	-1.5	0	- .5	▲ - .5	-1.5	- .5	-1	0	- .5	+2	-2	+1	-1	+ .5	- .5
	DOSIMETER	+1	+2.5							-1	-1	-1	- .3	0	+ .5	-1	-1	- .5	0	+1	+1.5	-1	+1	-1	+2	+2	+3.5

▲BEST FIT HELMET

TABLE 1 RELATIVE SPL FOR EAR BUG AND DOSIMETER USING 500 HZ PURE TONE - RELATIVE TO MICROPHONE AT CENTRE OF HEAD

SUBJECT		NO HELMET		SMALL HELMET						MEDIUM HELMET						LARGE HELMET						X-LARGE HELMET					
				ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR	
		FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR
1	EAR BUG	+4	-3	▲ 0	-6.5	+1	-6.5	+1	-4.5							0	-6.5	- .5	-6.5	- .5	-6						
	DOSIMETER	+4	-4	-3	-11	-3	-12	-1.5	-10							-2	-9	0	-10	+1.3	-7						
2	EAR BUG	+5	-1							-6.5	-8	-7	-8	-6	-8	▲ -6	-8	-7	-8	-5	-7	-3.5	-5	-4	-4.5	-2.5	-4
	DOSIMETER	+3.5	-3.8							-6.5	-9	-6	-9	-3	-8	-7.2	-11	-7	-11	-4.5	-10	-5.4	-9	-5	-9	-3	-8.5
3	EAR BUG	+4.5	+1	-1.5	-6.5	+2	-4	0	-4.5	▲ -1.5	-5.5	0	-5.5	-1	-4	-1.5	-6	-1.5	-6.5	+ .5	-5.5						
	DOSIMETER	+4.5	-3	-3	-10	-2	-11	0	-8.5	- .5	-8	0	-7	+2.5	-4	-1	-11	- .5	-10	+1	-7						
4	EAR BUG	+4	-3.5	▲ -5	-13	-6	-13	-4	-12	-2.5	-8	-2	-9	-1.5	-8	-3	-9	-3	-8.5	-2	-7.5						
	DOSIMETER	+3	-4	-6	---	-5	---	-4	-11	0	-9	+ .5	-10	+2	-7.7	-1	-12	-1	-12	+1.2	-9						
5	EAR BUG	+1	-4.5	▲ -5	-8	-5	-10	-4	-9.5	-4.5	-7.5	-3.5	-5.5	-2.5	-5	-1.5	-6	-1	-6	-1.4	-5.5						
	DOSIMETER	+3	0	-5.5	-9	-5.5	-9	-4.5	-9	-3	-6	-3	-5.5	-1.5	-4.7	-3	-7	-3	-6	-1.5	-6						
6	EAR BUG	0	-5.5							-9	-12.5	-9.5	-12.5	-8.5	-12	▲ -9	-14	-8.5	-13.5	-8.5	-13	-6.5	-11.5	-6.5	-12	-5.5	-12
	DOSIMETER	+2.5	-5.5							+1	-7	+2	-7	+2	-4.5	-2.4	-11	-2	-12	0	-9	-2	-11	-1	-9	+1.5	-8
7	EAR BUG	+5	0							0	-5	0	-5.5	0	-5	▲ -2.5	-8.5	-3	-8.5	-2	-8	-4	-7	-3	-7.5	-3.5	-7.5
	DOSIMETER	- .4	-8							-7.4	-14	-7.4	-14	-5.5	-12	-9	--	-9	--	-7.4	--	-4	--	-6	-14	-4	-14
8	EAR BUG	+5.5	+5.5							-6.5	-6.5	-6	-6	-5.5	-6	▲ -4.5	-5.5	-4.5	-6	-4.5	-5.5	-2	-4.5	-2	-4.5	-2	-4
	DOSIMETER	+2	+1							-7.4	-7.4	-7.4	-7	-7.4	-6	-6	-7	-7	-7.4	-5.5	-6	-4	-5.5	-4	-5.5	-3	-5.5

▲ BEST FIT HELMET

TABLE 2 RELATIVE SPL FOR EAR BUG AND DOSIMETER USING BROADBAND NOISE - RELATIVE TO MICROPHONE AT CENTRE OF HEAD

	SMALL HELMET						MEDIUM HELMET						LARGE HELMET						X-LARGE HELMET					
	ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR	
	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR
SUBJECT 1	▲ -4	-1	-4	-2	-2	0							-4	-3	-3	-3	0	+ .5						
SUBJECT 2							-13	-2.5	-13	-2.5	-10	-1	▲ -6.5	-2.5	-6.5	-2.5	-5	-1.5	-2.5	+1	-1.5	+1.5	- .5	+1.5
SUBJECT 3	-4.5	-2.5	-5	-2	-4.5	-1.5	▲ -4.5	- .5	- .5	+1.5	0	+3.5	+ .5	--	- .5	-1.5	-2.5	+ .5						
SUBJECT 4	▲ -7	-6	-6.5	-6.5	-5	-5	-7	-6	-7	-6	-6	-5	-5	-7	-5	-4	-3	-2						
SUBJECT 5	▲ -3	-4	-7	-1	-3	-1	-6.5	0	-6	-1	-5	+ .5	-6.5	-1.5	-5.5	-1.5	-4.5	-1.5						
SUBJECT 6							-2.5	+3	-2.5	+1	- .5	+3	▲ -5	+ .5	-4	+1	-3	+1.5	-5	+1.5	-5	+2	-3.5	+3
SUBJECT 7							-4.5	0	-5.5	-1	-3	- .5	▲ -5	-1	-6.5	-1.5	-4.5	-1	-2.5	+1	-2.5	+ .5	-1.5	+1
SUBJECT 8							-2.5	-2.5	-2	-1.5	-1	- .5	▲ -1.5	-1.5	- .5	-1	-1	- .5	+1	-2	0	-1	- .5	- .5

▲BEST FIT HELMET

TABLE 3 RELATIVE SPL FOR EAR BUG USING 500 Hz PURE TONE - RELATIVE TO HEAD WITH NO HELMET

	SMALL HELMET						MEDIUM HELMET						LARGE HELMET						X-LARGE HELMET					
	ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR		ONLY		PEAK		VISOR	
	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR	FRONT	REAR
SUBJECT 1	▲ -4	-3.5	-3	-3.5	-3	-1.5							-4	-3.5	-4.5	-3.5	-4.5	-2						
SUBJECT 2							-11.5	-7	-12	-7	-11	-6.5	▲ -11	-7	-12	-7	-10	-6	-8.5	-4	-9	-3.5	-7.5	-3
SUBJECT 3	-6	-7.5	-2.5	-5	-4.5	-5.5	▲ -6	-6.5	-4.5	-6.5	-5.5	-5	-6	-7	-6	-7.5	-4	-6.5						
SUBJECT 4	▲ -9	-9.5	-10	-9.5	-8	-8.5	-6.5	-4.5	-6	-5.5	-5.5	-4.5	-7	-5.5	-7	-5	-6	-4						
SUBJECT 5	▲ -6	-3.5	-6	-5.5	-5	-5	-5.5	-3	-4.5	-1	-3.5	-.5	-2.5	-1.5	-2	-1.5	-2.5	-1						
SUBJECT 6							-9	-7	-9.5	-7	-8.5	-6.5	▲ -9	-8.5	-8.5	-8	-8.5	-7.5	-6.5	-6	-6.5	-6.5	-5.5	-6.5
SUBJECT 7							-5	-5	-5	-5.5	-5	-5	▲ -7.5	-8.5	-8	-8.5	-7	-8	-9	-7	-8	-7.5	-8.5	-7.5
SUBJECT 8							-12	-12	-11.5	-11.5	-11	-11.5	▲ -10	-11	-10	-11.5	-10	-11	-7.5	-10	-7.5	-10	-7.5	-9.5

▲ BEST FIT HELMET

TABLE 4 RELATIVE SPL FOR EAR BUG USING BROADBAND NOISE - RELATIVE TO HEAD WITH NO HELMET

SNOWMOBILES			
VEHICLE	MODEL YEAR	TYPE	ENGINE DISPLACEMENT
A	1972	SNOW JET SST	295cc
B	1976	ALPINE TWIN-TRACK	399cc
C	1971	SNOW JET	292cc
D	1974	SNOW JET	292cc
E	1975	ALOUETTE	340cc
F	1974	MOTO SKI CAPRI	295cc
G	1974	MOTO SKI FUTURA	295cc
H	1973	ARCTIC CAT ELTIGRA	250cc
J	1973	MOTO SKI CAPRI	340cc
K	1973	SKI DOO OLYMPIC	340cc

TABLE 5 SPECIFICATIONS OF SNOWMOBILES USED IN THIS STUDY

MOTORCYCLES			
VEHICLE	MODEL YEAR	TYPE	ENGINE DISPLACEMENT
1	1975	ROKON	340cc
2	1972	HONDA	450cc
3	1972	YAMAHA	400cc
4	1968	TRIUMPH	650cc
5	1972	SUZUKI	380cc
6	1974	KAWASAKI	500cc

TABLE 6 SPECIFICATIONS OF MOTORCYCLES USED IN THIS STUDY

VEHICLE	MODEL YEAR		ISO_8 (%)		$OSHA_8$ (%)			L_{eq} (dBA)		
			B&K	EAR BUG	G.R.	B&K	EAR BUG	G.R.	B&K	EAR BUG
A	1972			159			116			92
B	1976			228		80 mod	152		89	94
C	1971			1944			548			103
D	1974				214			96		
E	1975		668 mod						93	
F	1974				318			99		
G	1974				466			101		
H	1973					357		100		
J	1973		3290 mod						100	
K	1973					344			101	

TABLE 7 RESULTS OF SNOWMOBILE NOISE EXPOSURE TESTS

VEHICLE	MODEL YEAR	*	ISO_8 (%)		$OSHA_8$ (%)			L_{eq} (dBA)		
			B&K	EAR BUG	G.R.	B&K	EAR BUG	G.R.	B&K	EAR BUG
1	1975	C		339		102	173		92	95
1	1975	H		295	160		164	94		95
2	1972	C		96		86	61		89	90
2	1972	C		309		182	172		94	95
2	1972	C		253		67	132		87	94
2	1972	H			304	336		98	99	
2	1972	C				67 mod / 38			87 / 84	
2	1972	H	6964 mod / 2400						103 / 104	
2	1972	H	672			211			98 ISO / 96	
2	1972	C	154			38			92 ISO / 83	

*H–HIGHWAY DRIVING
C–CITY DRIVING

TABLE 8 RESULTS OF MOTORCYCLE NOISE EXPOSURE TESTS

VEHICLE	MODEL YEAR	*	ISO_8 (%)		$OSHA_8$ (%)			L_{eq} (dBA)		
			B&K	EAR BUG	G.R.	B&K	EAR BUG	G.R.	B&K	EAR BUG
3	1976	C			81	54		88	85	
3	1976	H	328			127			95 ISO / 99	
3	1976	C	38						86	
3	1976	H	149			117			92 / 92	
4	1968			79		259	64		97	89
5	1972	C			48	0		85		
5	1972	C			48	0		85		
5	1972	H			107	75		90	88	
5	1972	H	76	265	163		152	94	89	94
5	1972	H	96	219	144		139	93	90	93

*H–HIGHWAY DRIVING
C–CITY DRIVING

TABLE 8 CONTINUED

VEHICLE	MODEL YEAR	*	ISO_8 (%)		$OSHA_8$ (%)			L_{eq} (dBA)		
			B&K	EAR BUG	G.R.	B&K	EAR BUG	G.R.	B&K	EAR BUG
5	1972	H	422	1103	230		382	96	96	100
5	1972	H	96 mod / 38						85 / 86	
5	1972	H	768 mod / 412						94 / 95	
6	1974	C		107		19	81		<80	90
6	1974	C		193	115		128	92		93
6	1974	H		385	202		200	95		96
6	1974	C		193	115		127	91		93
6	1974	H	480	1000			362		97	100
6	1974	H	597	680			285		98	98
6	1974	C	77			48			89 ISO / 85	

*H—HIGHWAY DRIVING
C—CITY DRIVING

TABLE 8 CONTINUED

VITA AUCTORIS

1949	Born in Windsor, Ontario, Canada on January 20.
1968	Completed High School at Assumption Collegiate School, Windsor, Ontario, Canada in June.
1972	Received the Degree of Bachelor of Applied Science in Mechanical Engineering from the University of Windsor, Windsor, Ontario, Canada in May.
1972 to 1974	Employed as a Manufacturing Engineer by the Ford Motor Company of Canada, Windsor, Ontario, Canada.
1976	Currently a candidate for the Degree of Master of Applied Science in Mechanical Engineering at the University of Windsor, Windsor, Ontario, Canada.